FROM THE TOP TO THE HIGGS AND BEYOND

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INFN Istituto Nazionale di Fisica Nucleare

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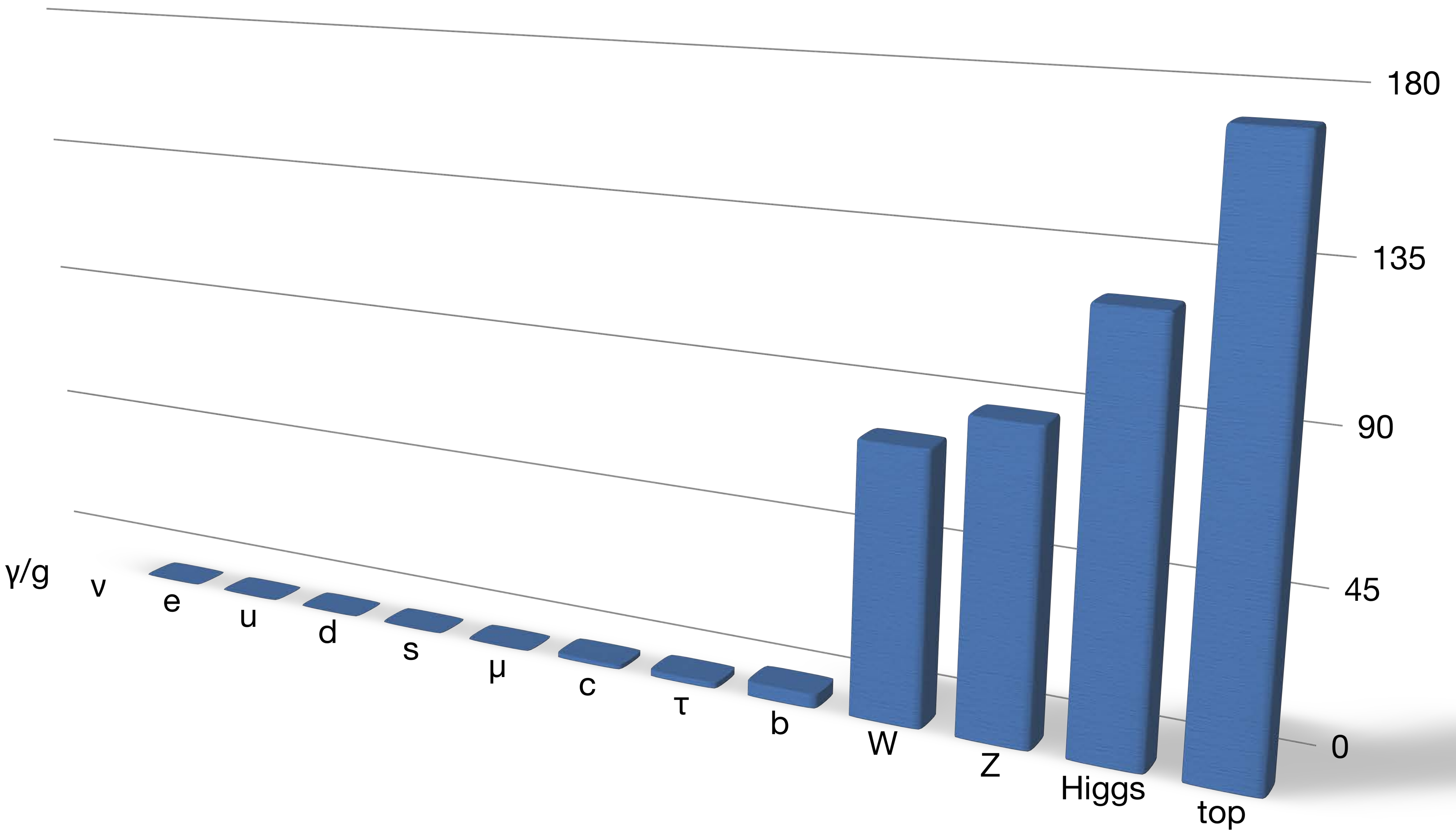
Why Top and Higgs?



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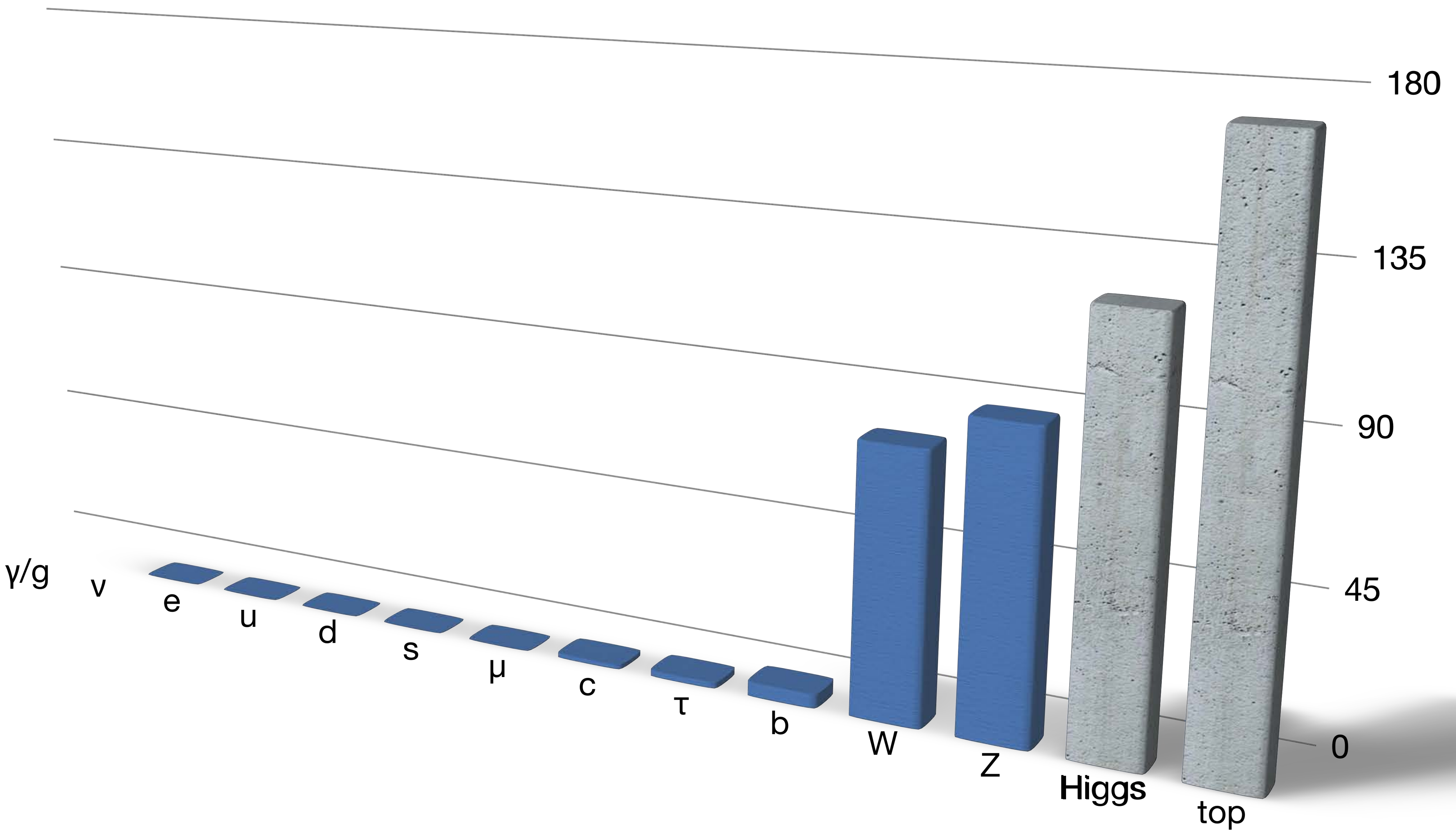
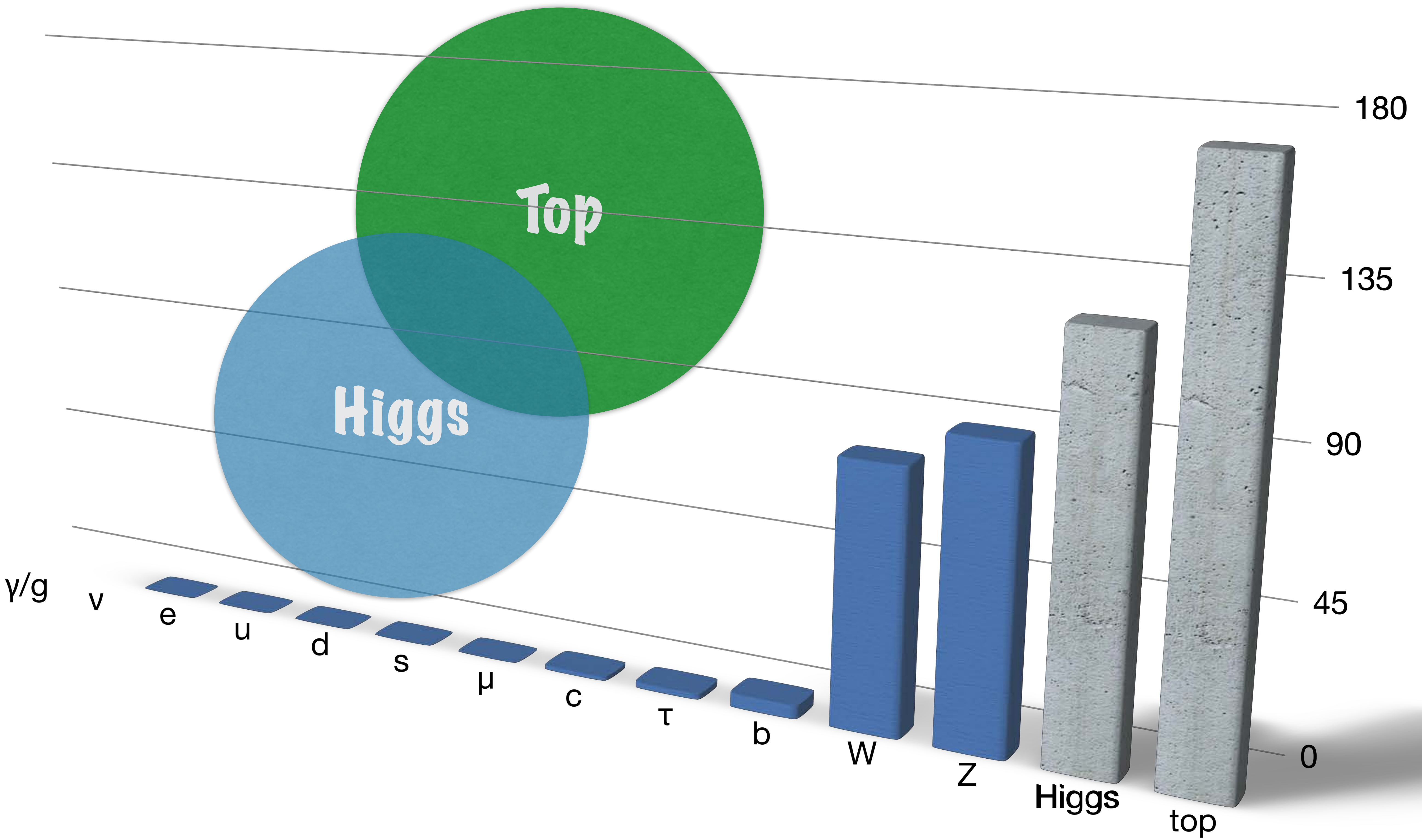
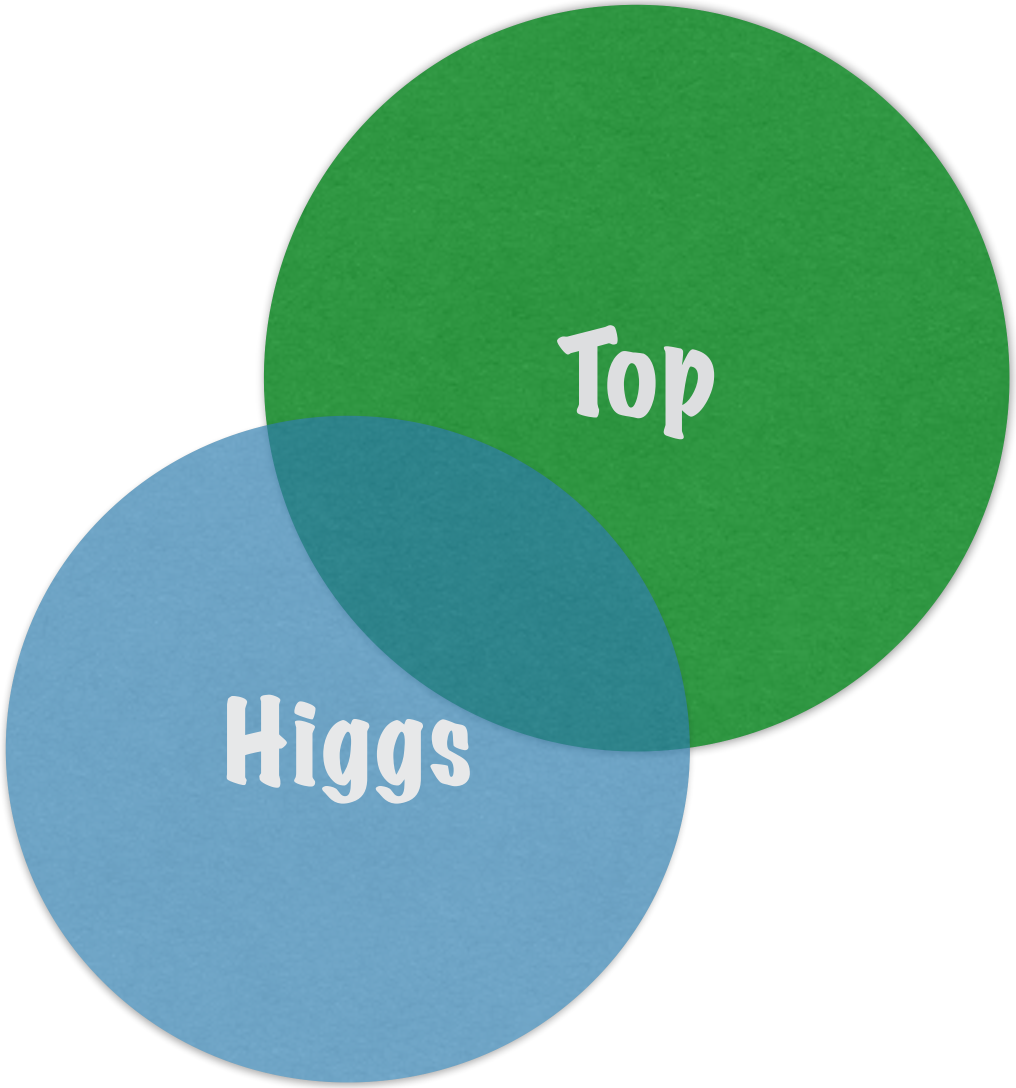
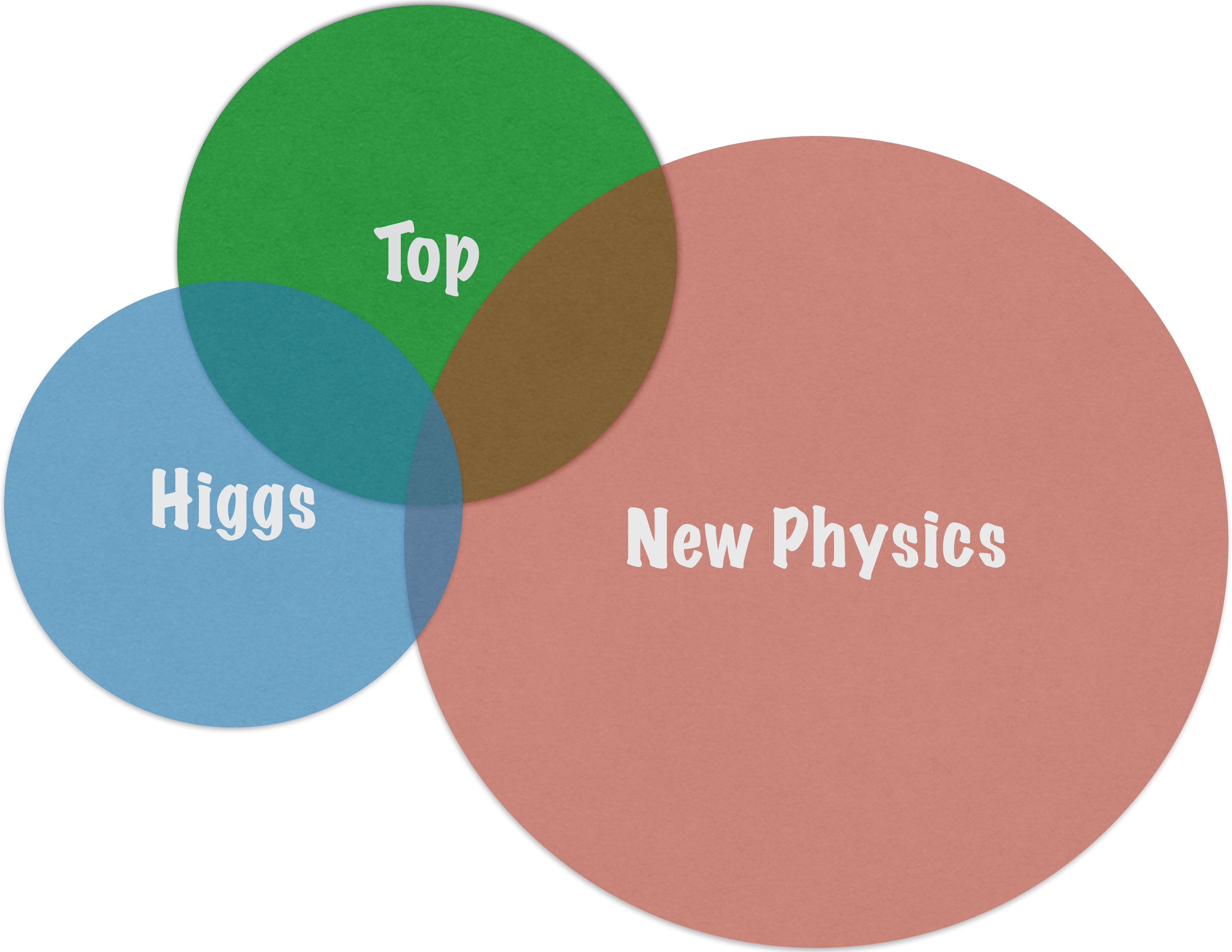
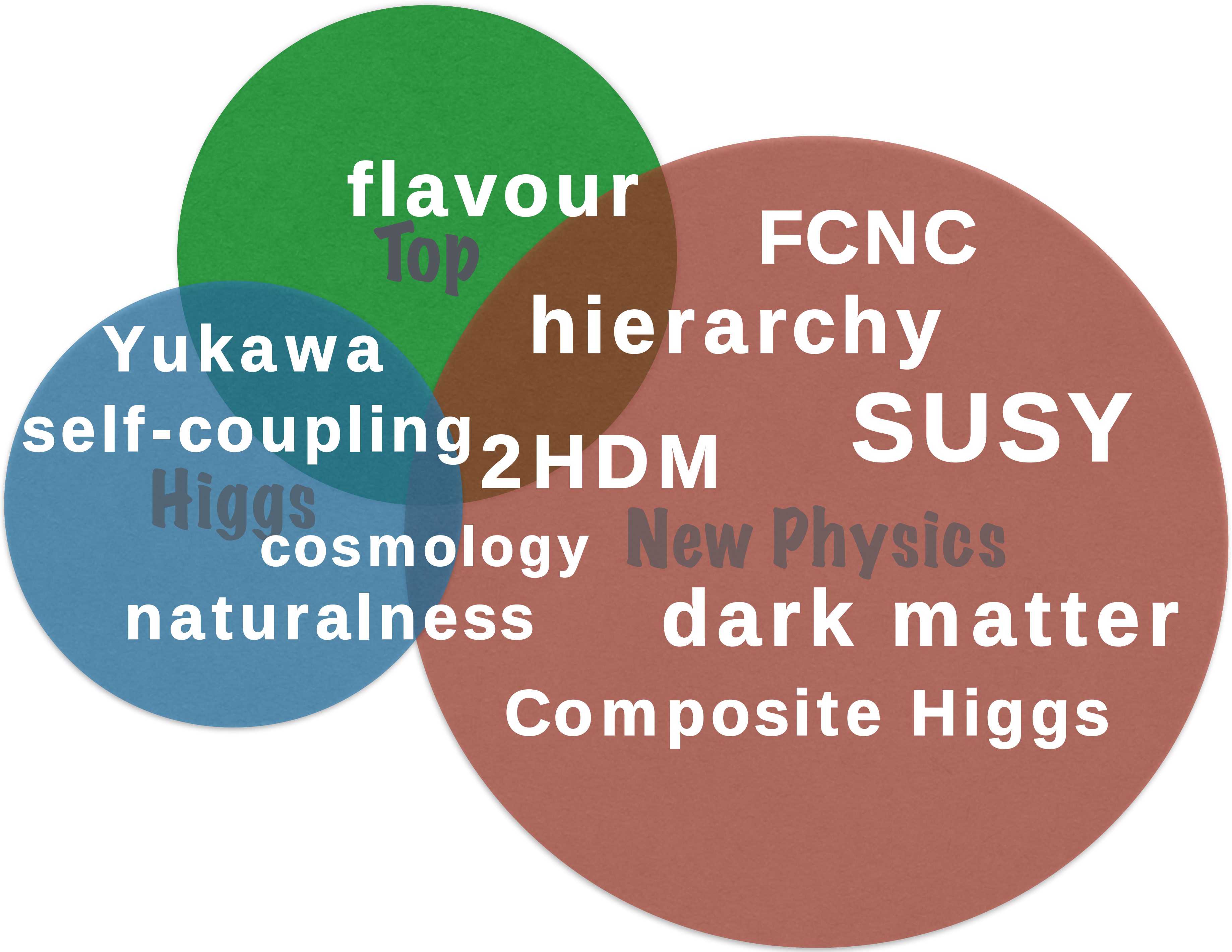


Why Top and Higgs?

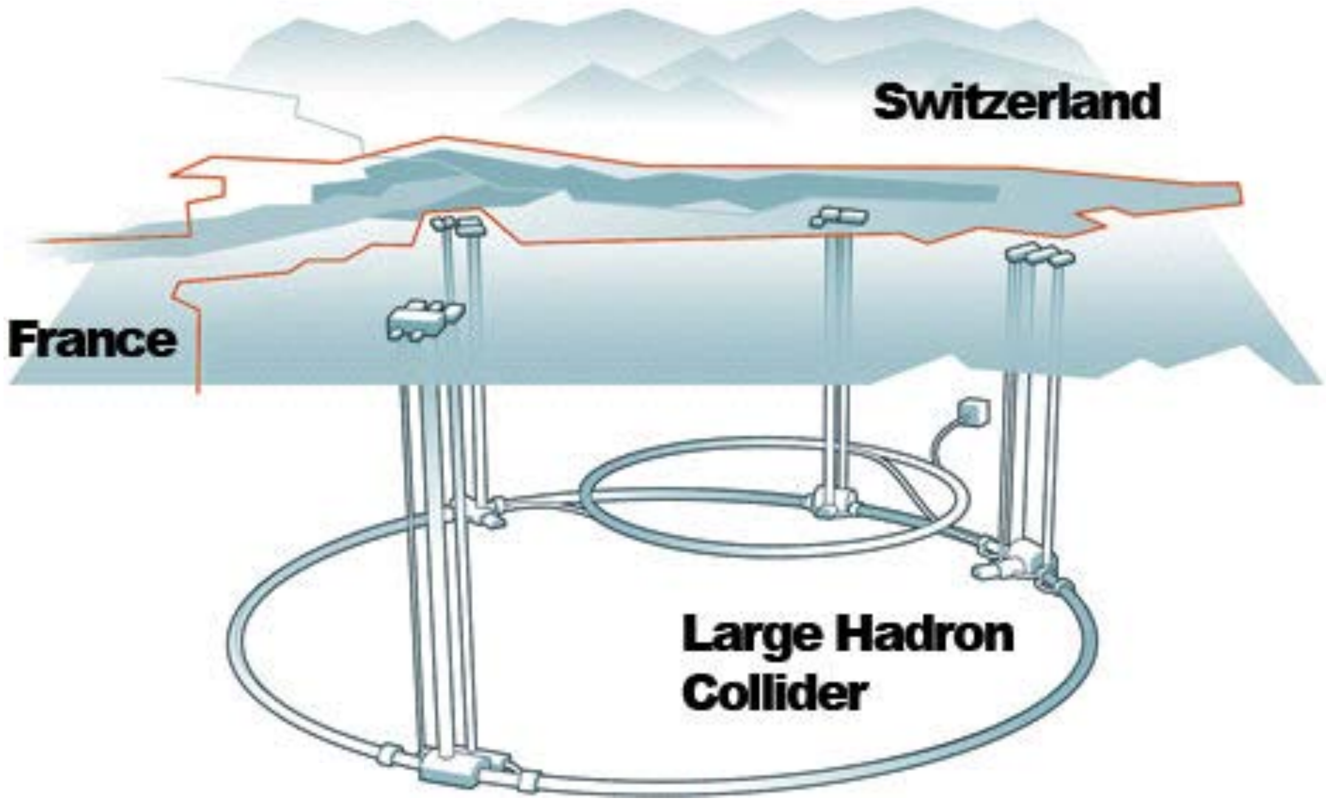



Top
Higgs

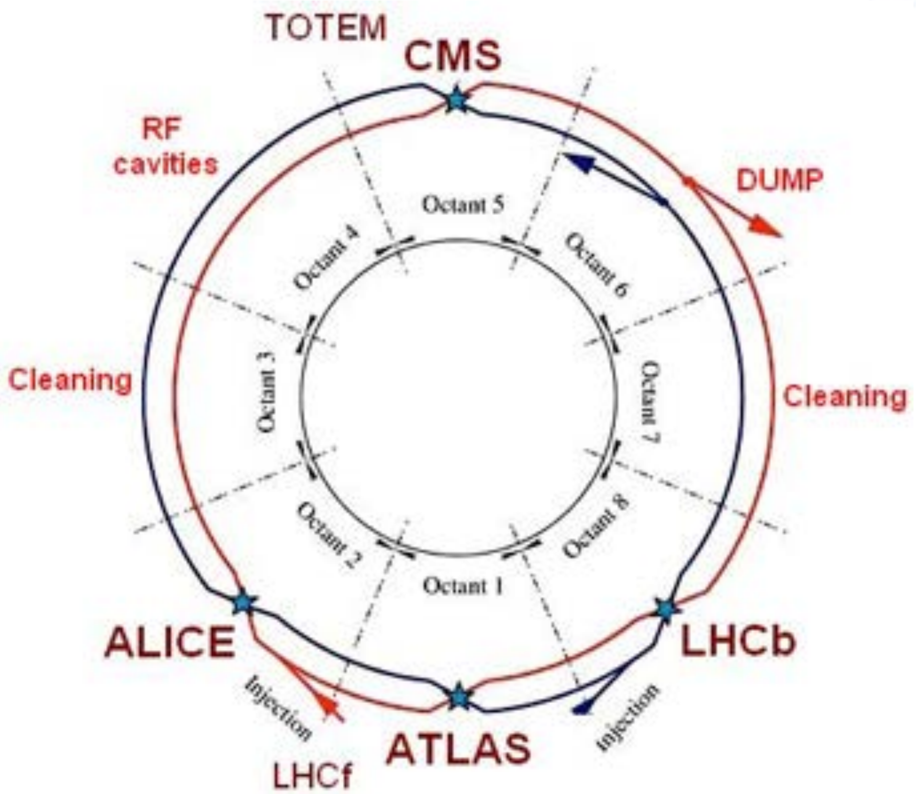

Top
Higgs
New Physics


flavour
Top
FCNC
hierarchy
Yukawa
SUSY
self-coupling
2HDM
Higgs
New Physics
cosmology
dark matter
naturalness
Composite Higgs

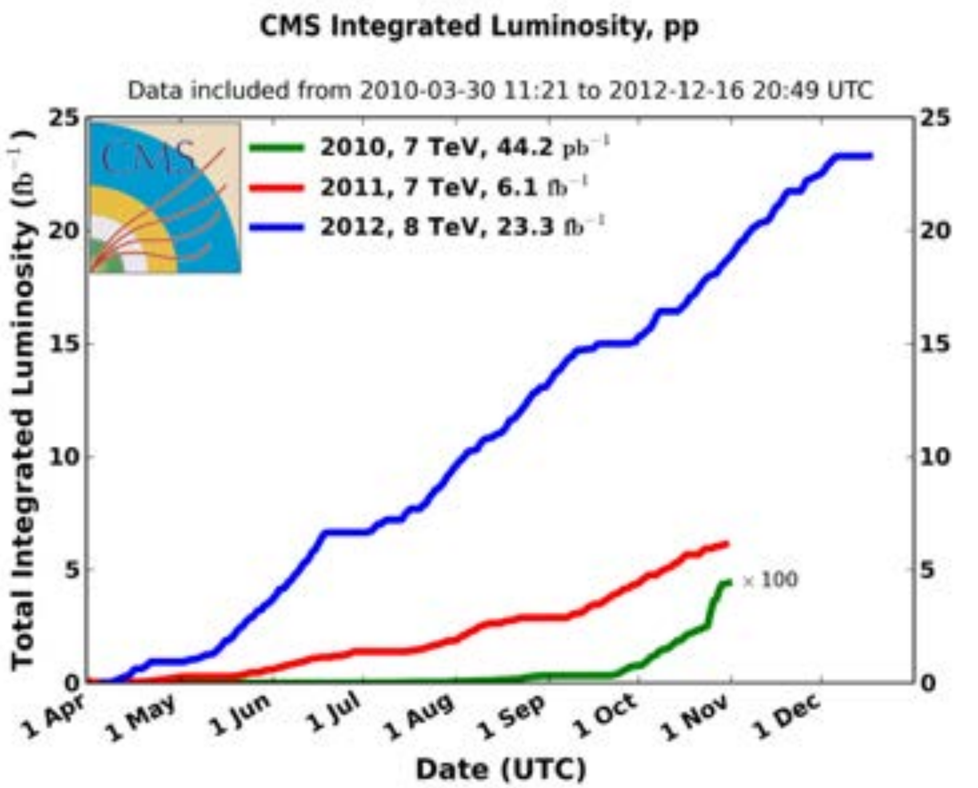
WHERE



Switzerland
France
Large Hadron Collider

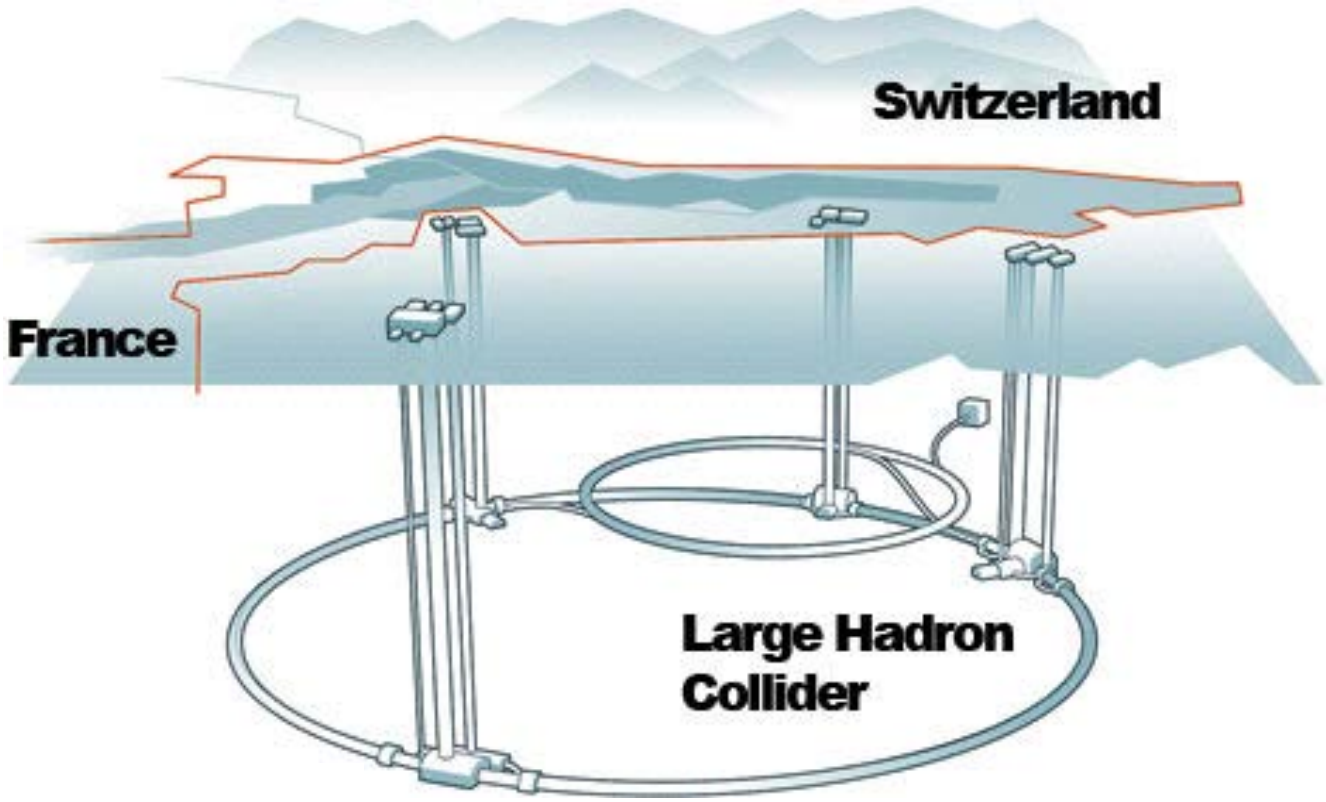


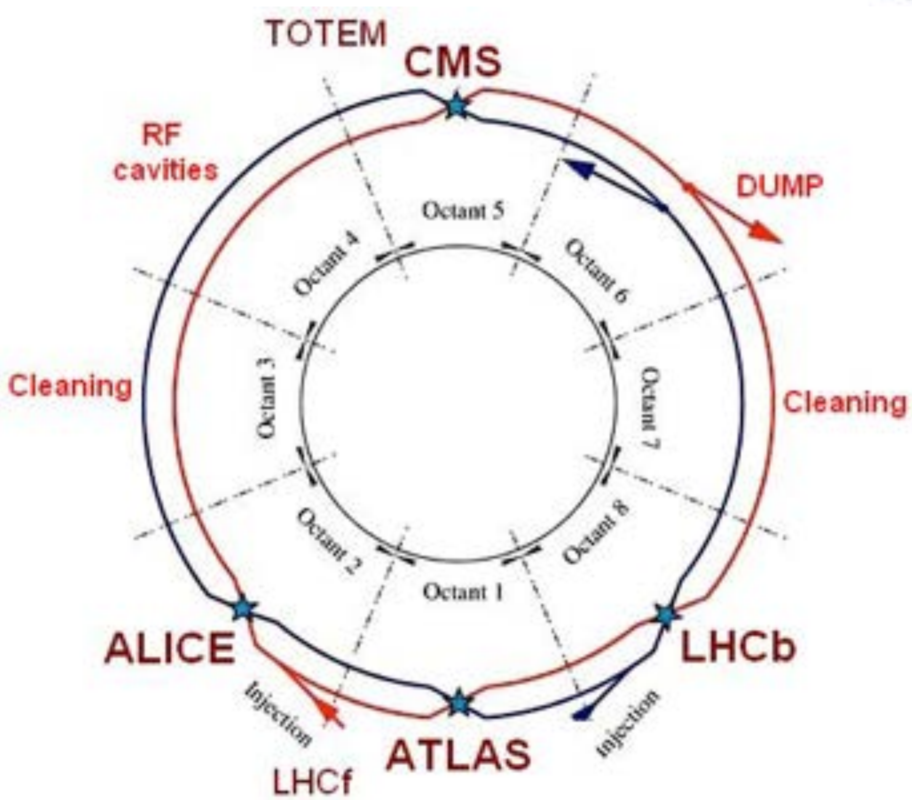
TOTEM
CMS
RF cavities
DUMP
Octant 5
Octant 4
Octant 6
Octant 3
Octant 7
Octant 2
Octant 8
Octant 1
Cleaning
Cleaning
ALICE
LHCb
Injection
Injection
LHCf
ATLAS

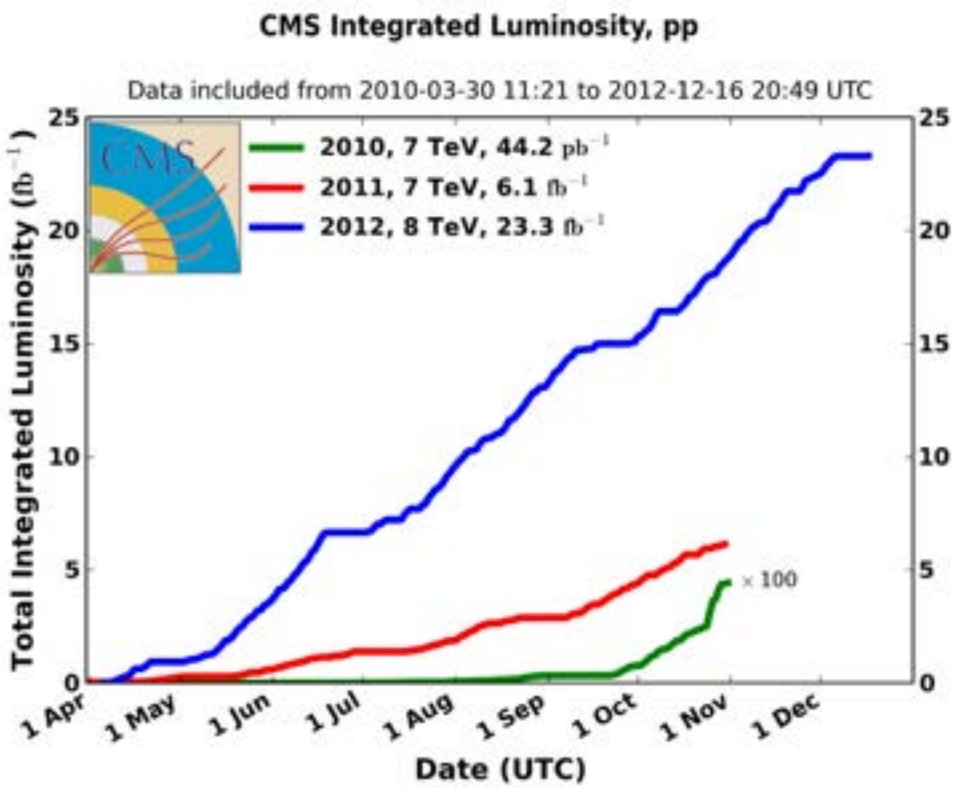


CMS Integrated Luminosity, pp
Data included from 2010-03-30 11:21 to 2012-12-16 20:49 UTC
2010, 7 TeV, 44.2 pb⁻¹
2011, 7 TeV, 6.1 fb⁻¹
2012, 8 TeV, 23.3 fb⁻¹
× 100
Total Integrated Luminosity (fb⁻¹)
Date (UTC)
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec

WHERE

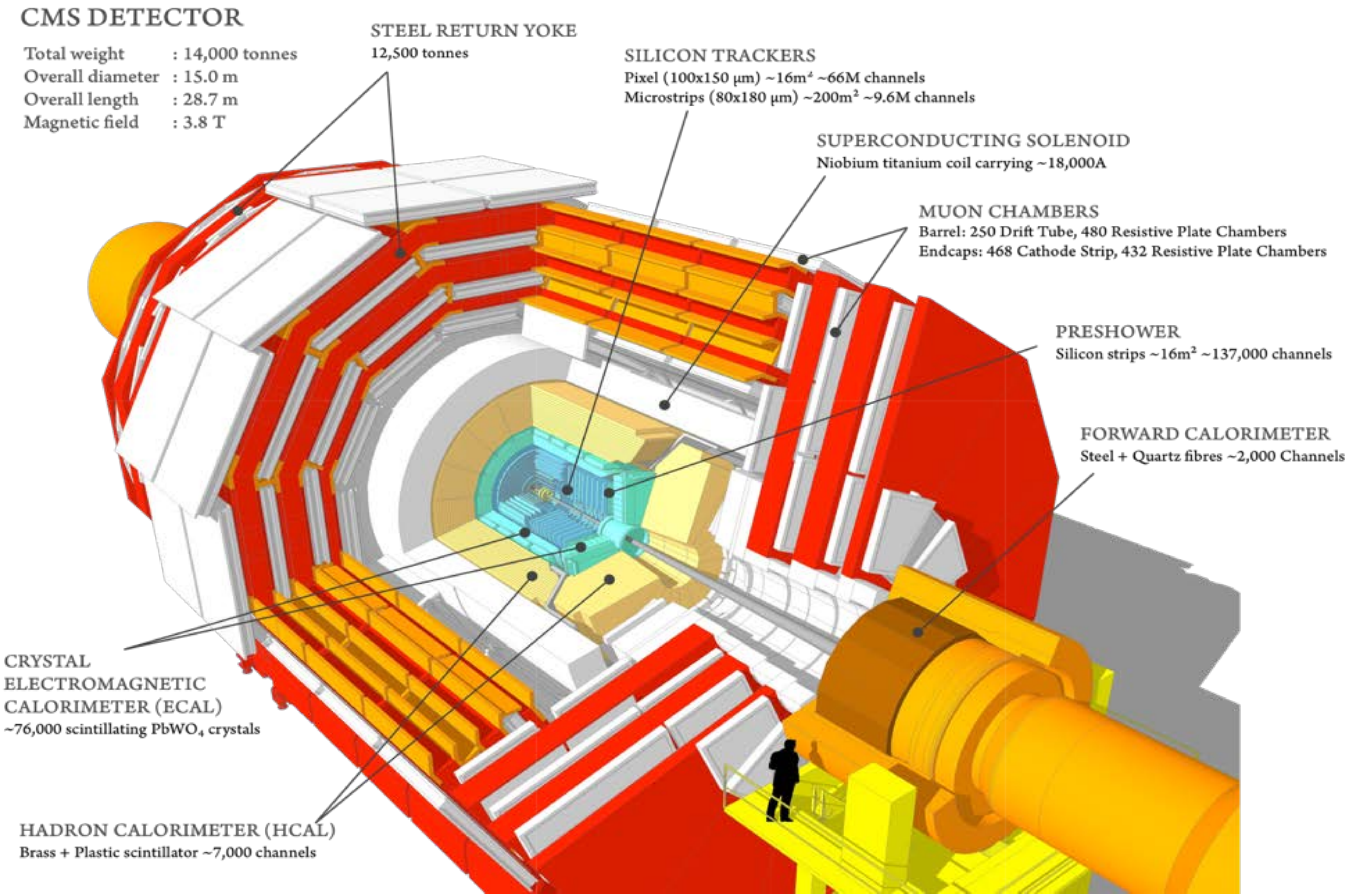






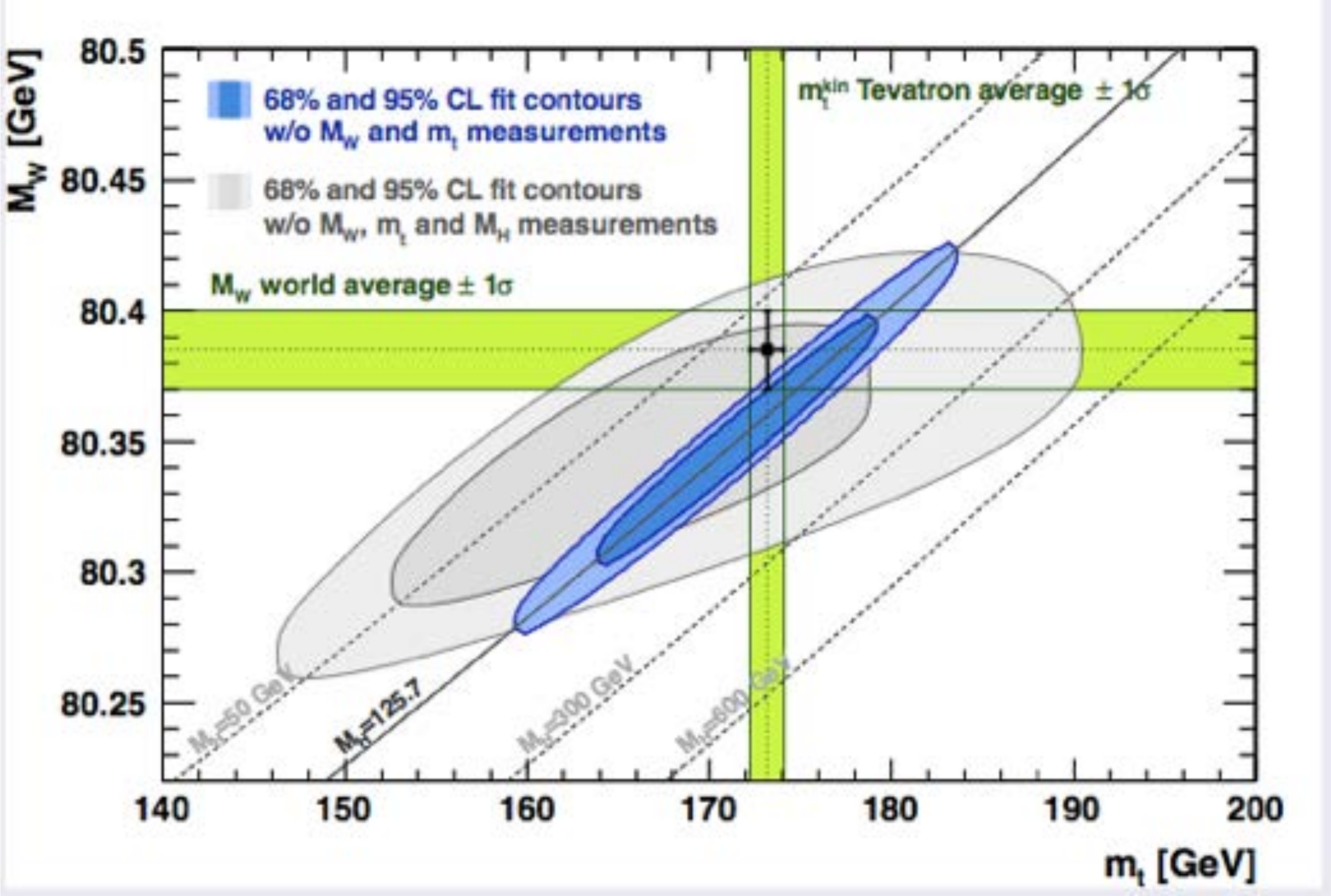
No 13TeV results on these topics yet

How


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

TOP, HIGGS, AND ALL OF US

- Precise top quark mass (and W boson mass) measurements provides a predictions for a SM Higgs boson mass: mH=94±24GeV

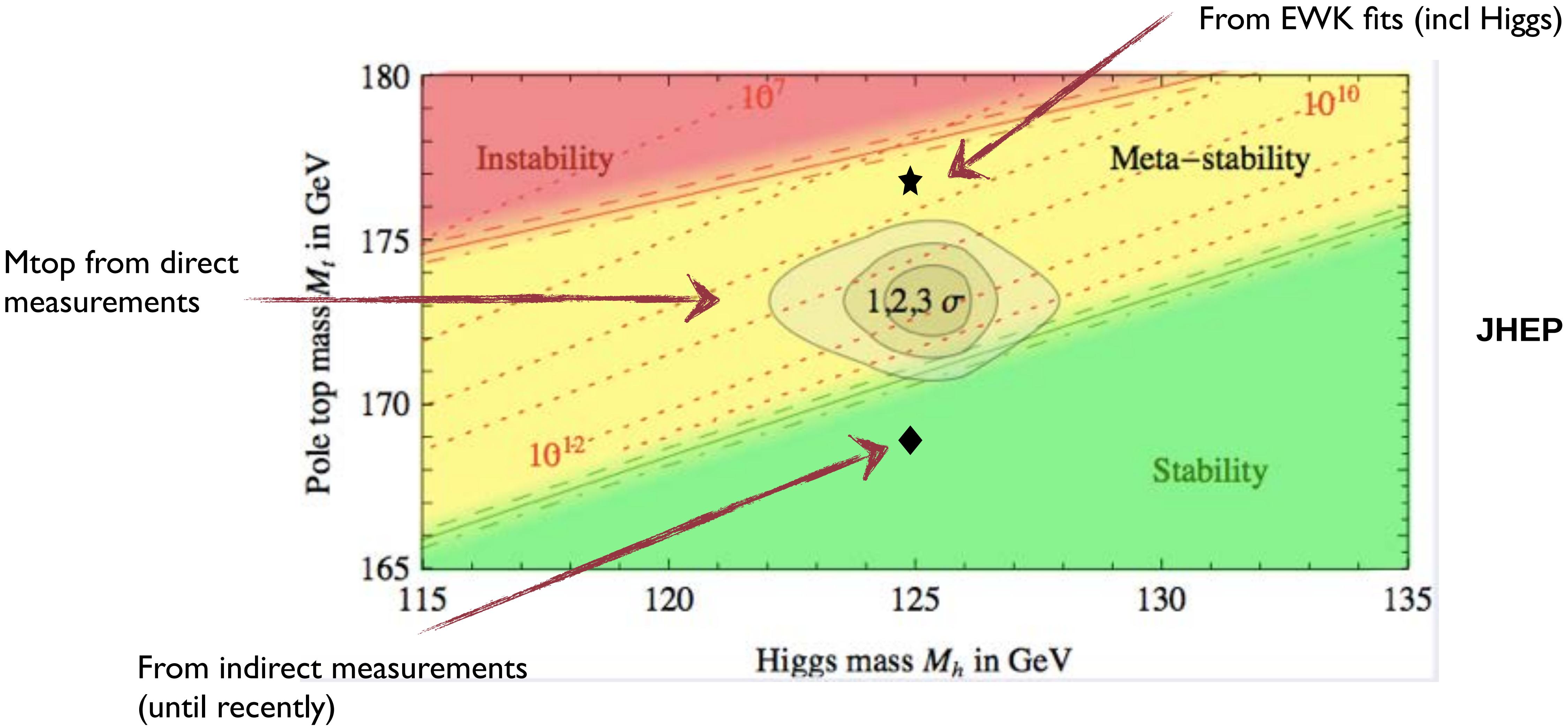


EPJ C72 2205

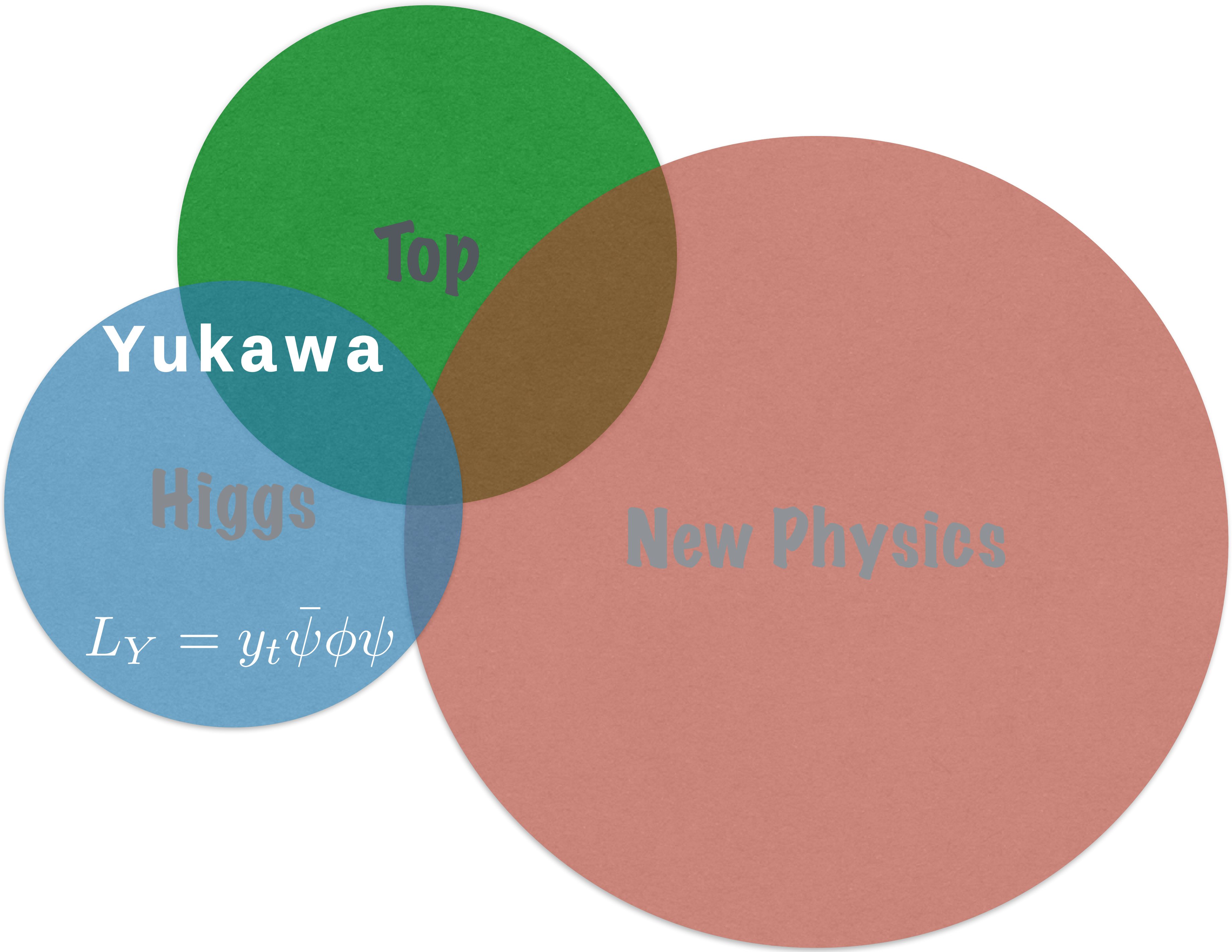
Predicted Higgs boson to be within 1sigma to where we found it!
Knowledge of Higgs mass allows prediction of Mtop to 1% level: Mtop=175.8±2.5GeV

TOP, HIGGS, AND ALL OF US

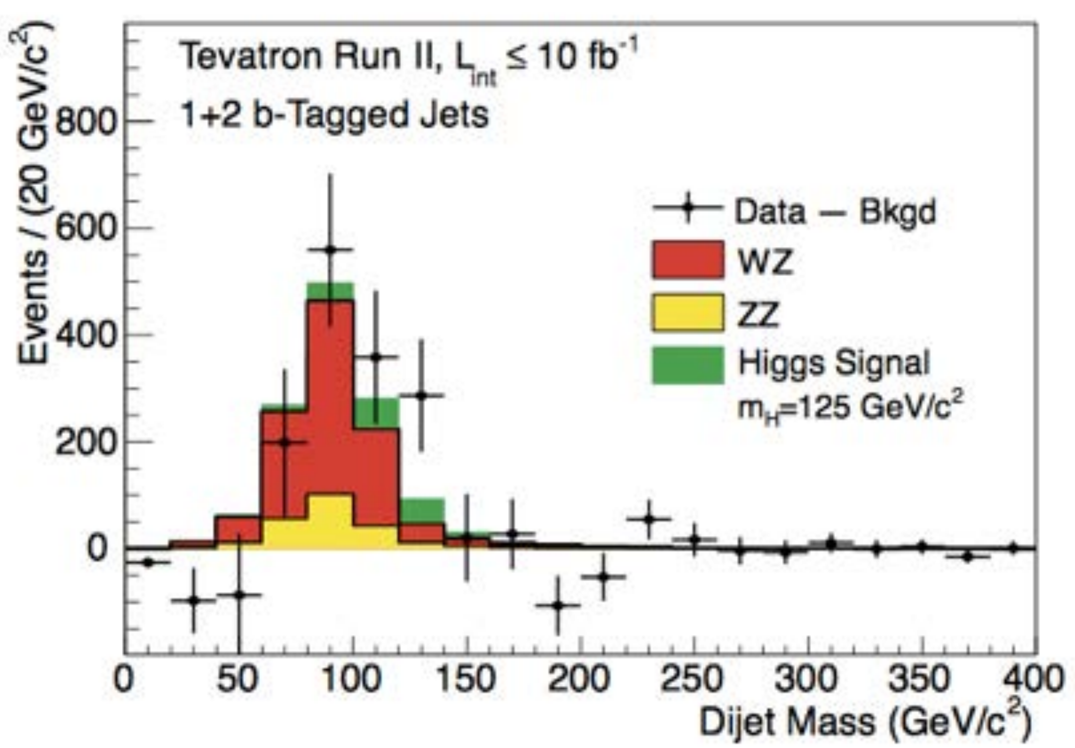
- Precise top quark mass (and W boson mass) measurements provides a predictions for a SM Higgs boson mass: mH=94±24GeV
- Oh BTW, it also helps us predict the fate of the universe...



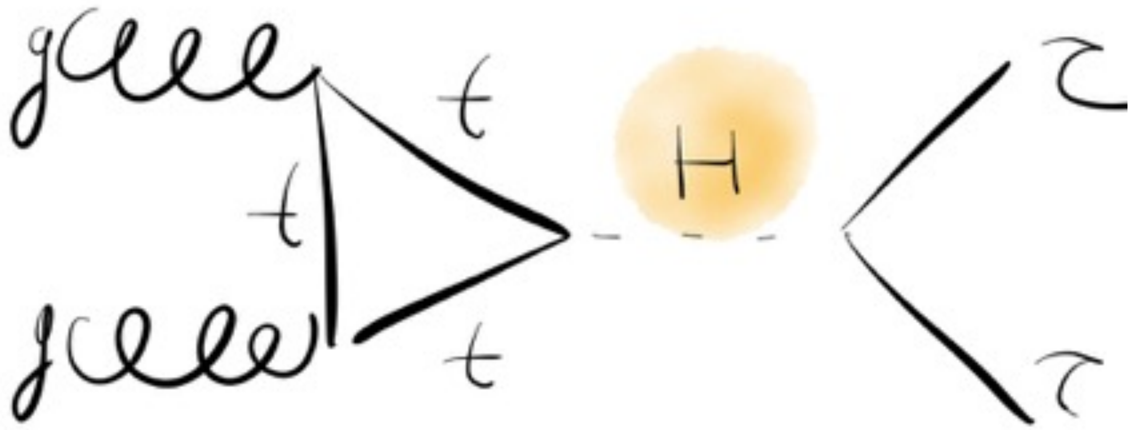
JHEP 1208 098

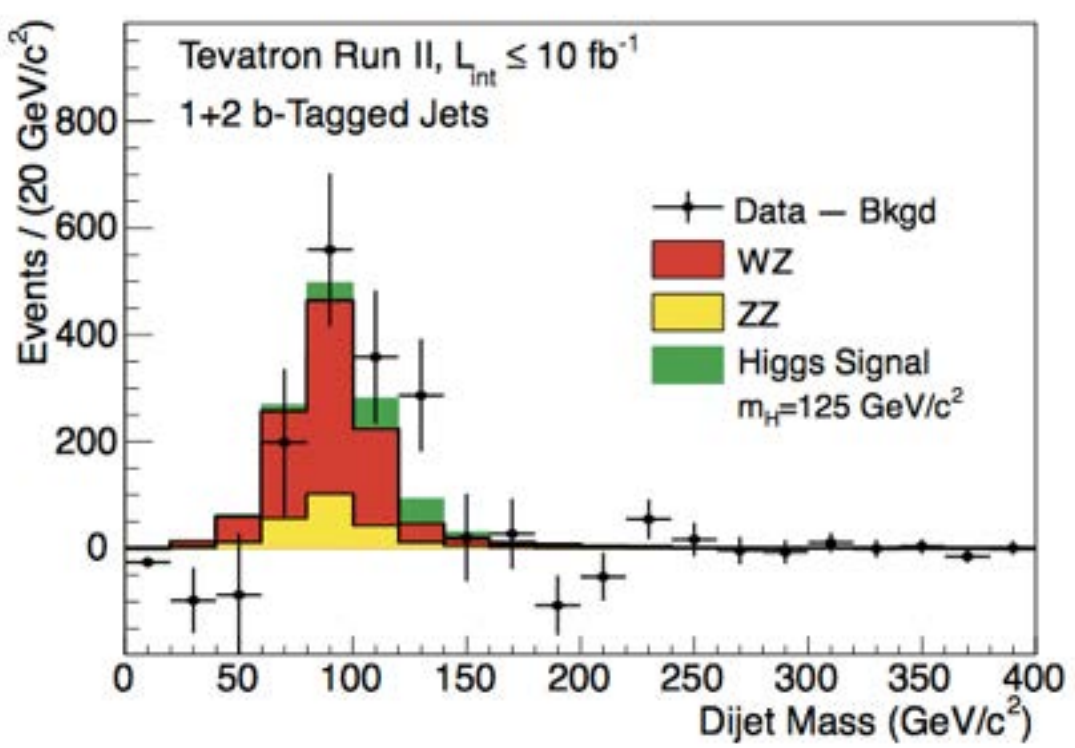

Top
Yukawa
Higgs
New Physics
$L_Y = y_t \bar{\psi} \phi \psi$

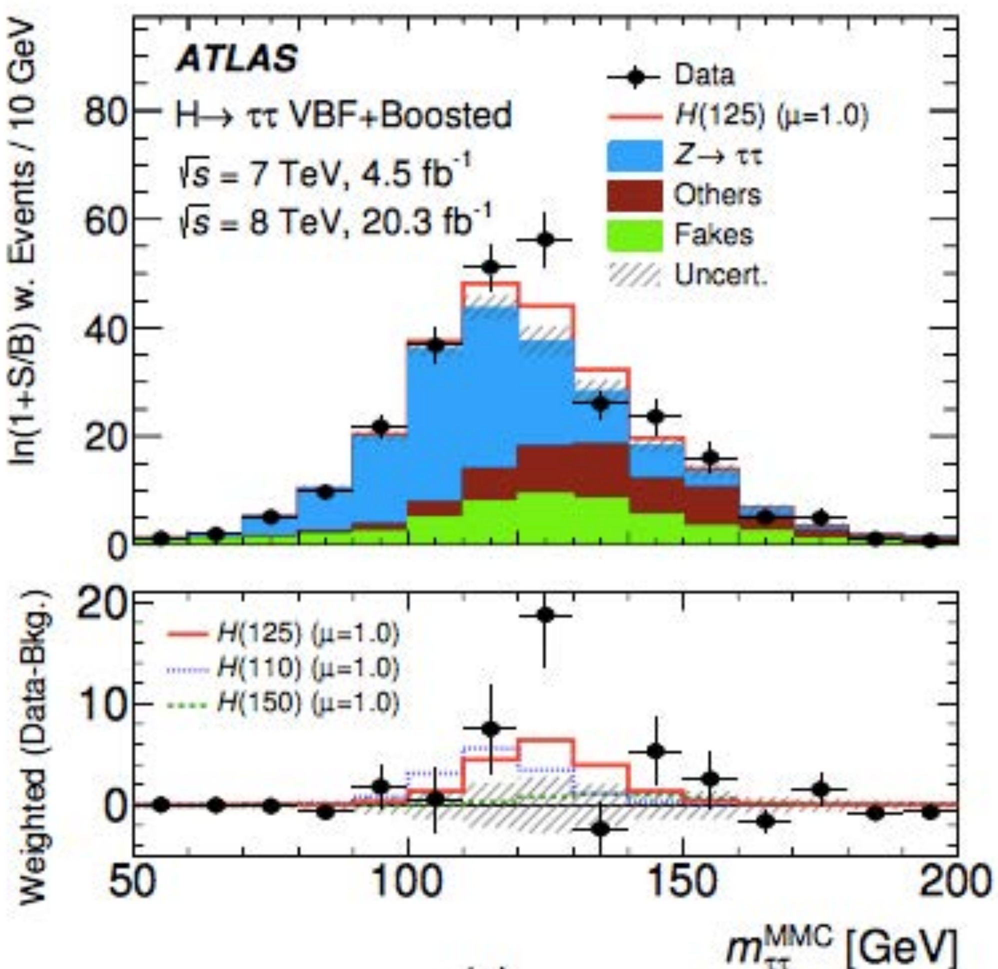
HIGGS AND FERMIONS: BOTTOMS(?)



HIGGS AND FERMIONS: TAUS(!)







(a)

A THREEFOLD WAY TO TOP+HIGGS

INDIRECT:

Direct Higgs Production
Higgs decay to photons

CMS EPJ. C 75 (2015) 212

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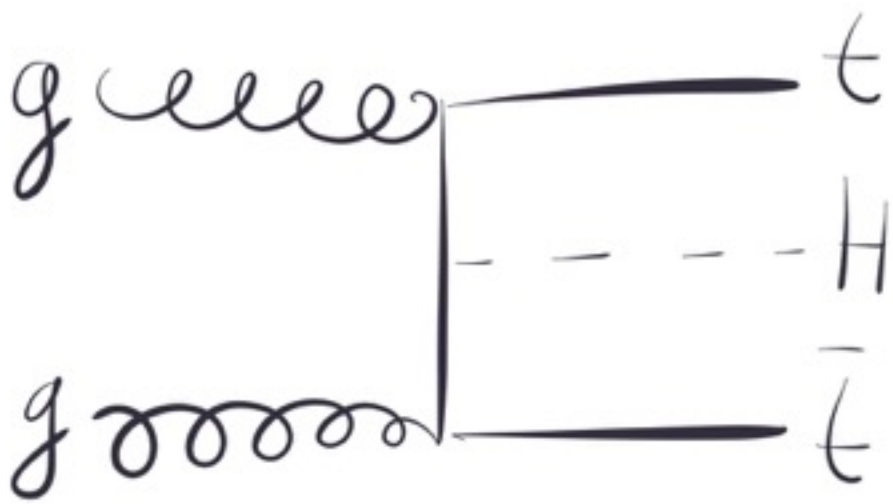


DIRECT: absolute Yukawa

Top-antitop-Higgs Production

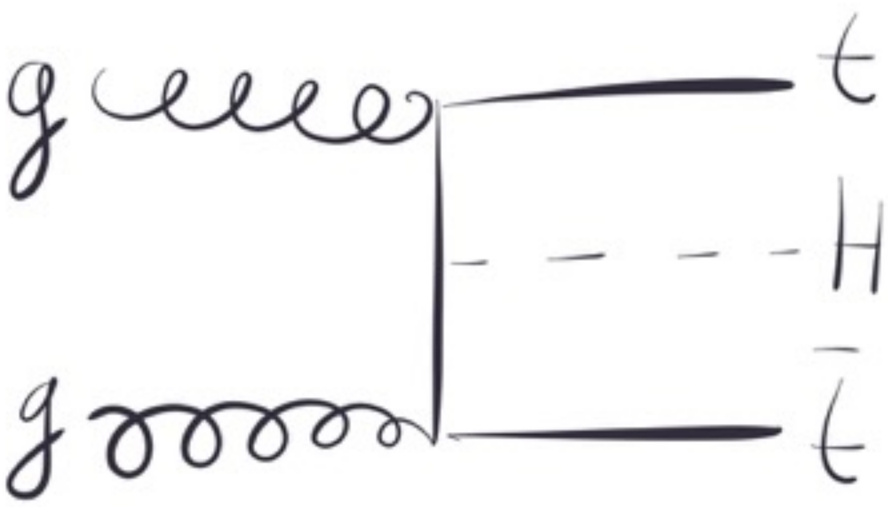
JHEP 09 (2014) 087 (*comb*)

EPJ C 75 (2015) (bb ME)

A THREEFOLD WAY TO TOP+HIGGS

INDIRECT:
Direct Higgs Production
Higgs decay to photons

CMS EPJ. C 75 (2015) 212

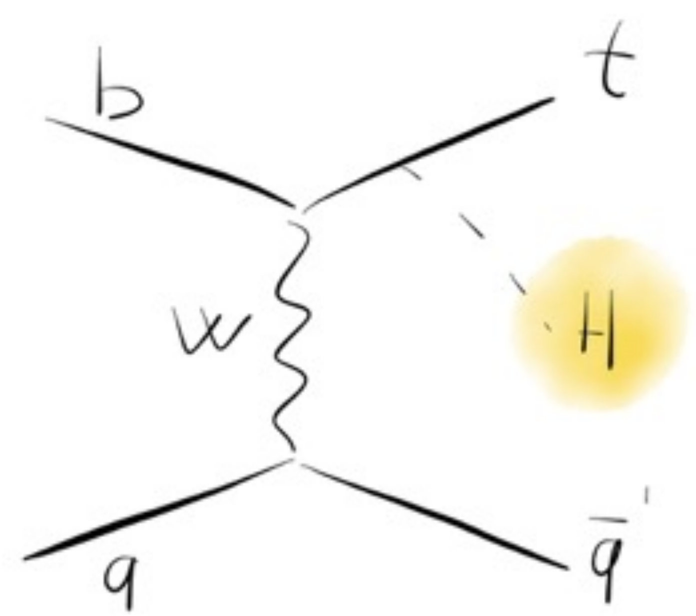


DIRECT: absolute Yukawa
Top-antitop-Higgs Production

JHEP 09 (2014) 087 (*comb*)
EPJ C 75 (2015) (bb ME)

DIRECT: Yukawa sign
Top(antitop)-Higgs Production

CMS-HIG-14-001 ($\gamma\gamma$)
CMS-HIG-14-015 (*bb*)
CMS-HIG-14-026 (*leptons*)
CMS-HIG-14-027 (*tau+combination*)



Higgs and fermions: tops

- We know there is a Higgs boson in LHC data

HIGGS AND FERMIONS: TOPS

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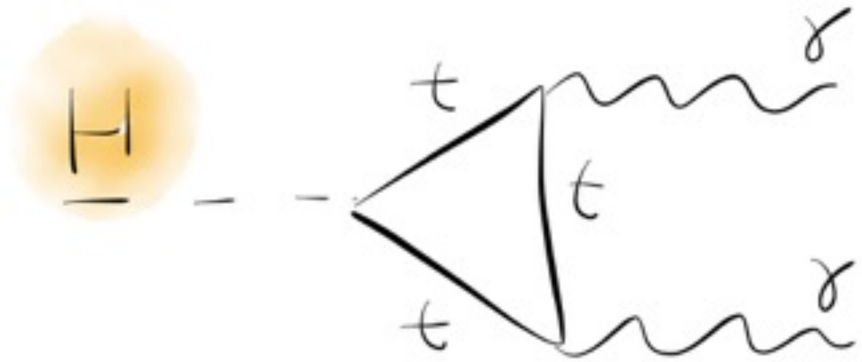
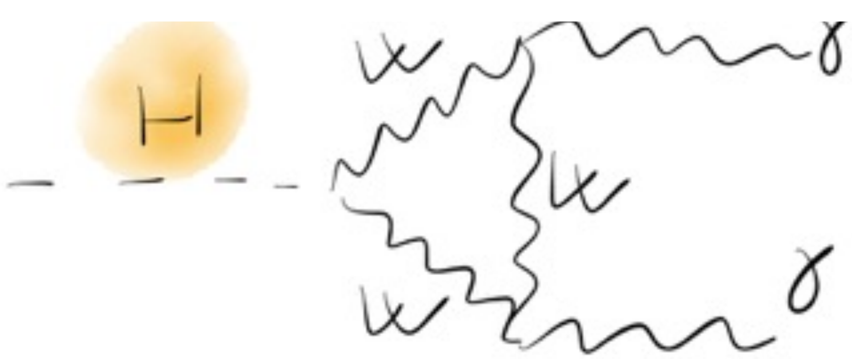
- it first appeared decaying into two bosons
- the big picture is still far from clear, as there are a multitude of loops where new physics might be hiding
- not to mention interference between diagrams…





HIGGS AND FERMIONS: TOPS

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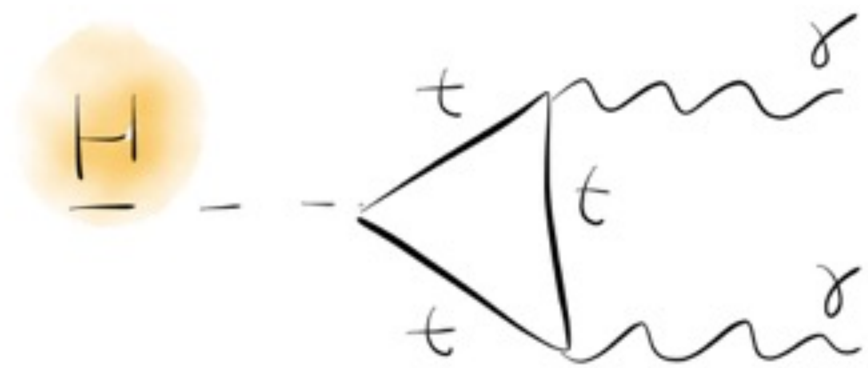
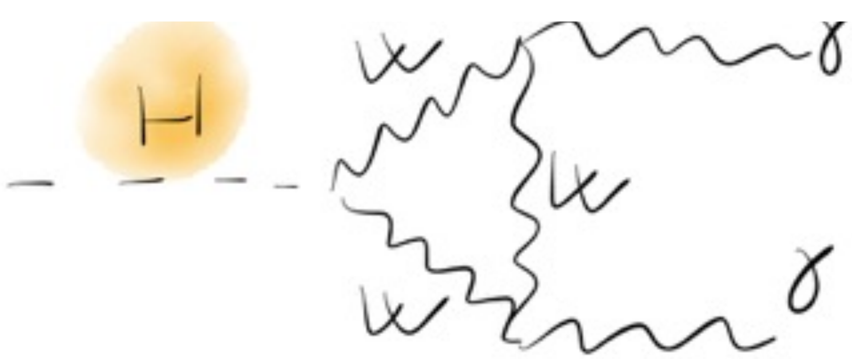
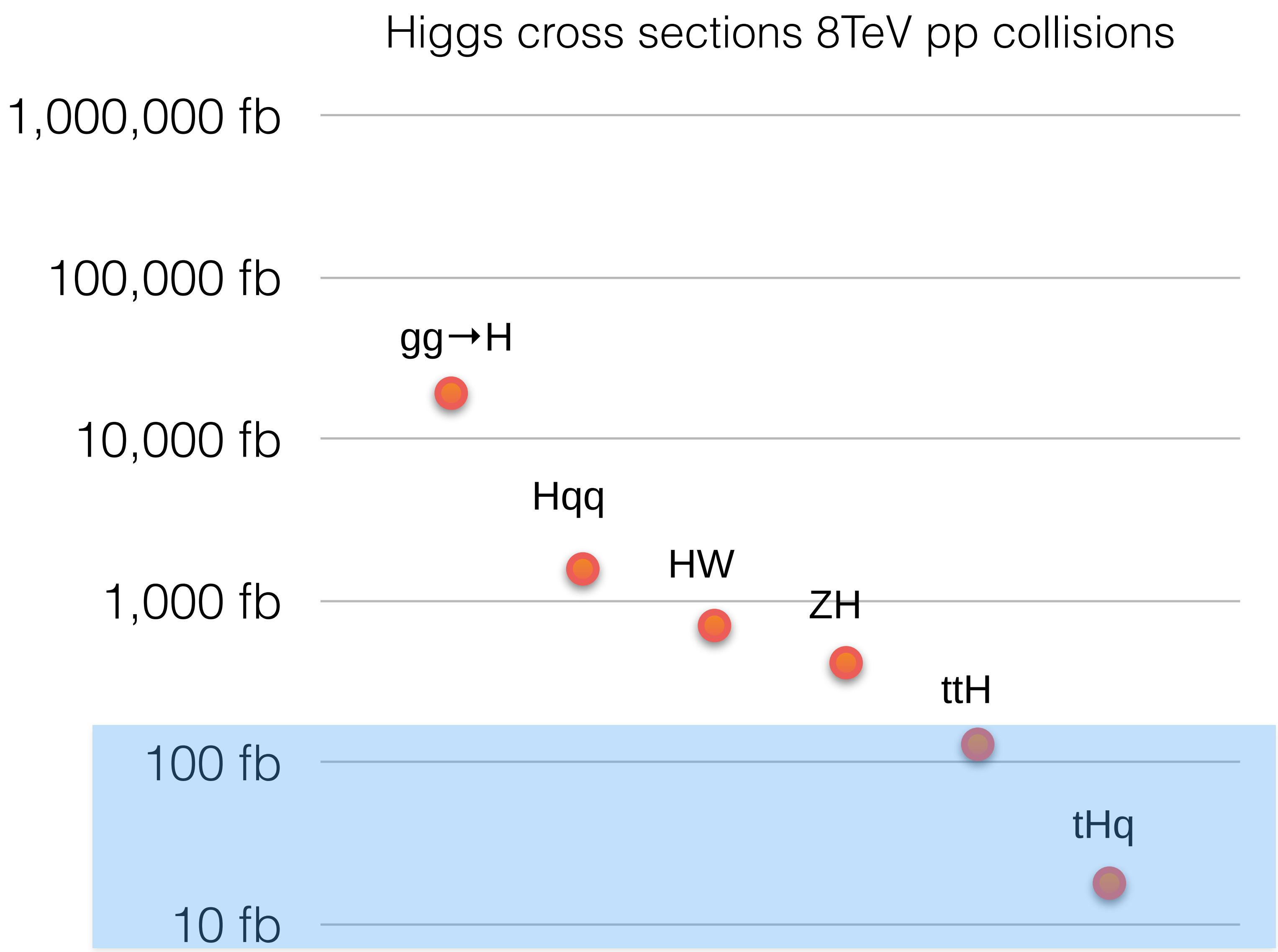
- it first appeared decaying into two bosons
- the big picture is still far from clear, as there are a multitude of loops where new physics might be hiding
- not to mention interference between diagrams…
- we do not "see" inside loops!





DIG DEEPER INTO THE LHC GOLD



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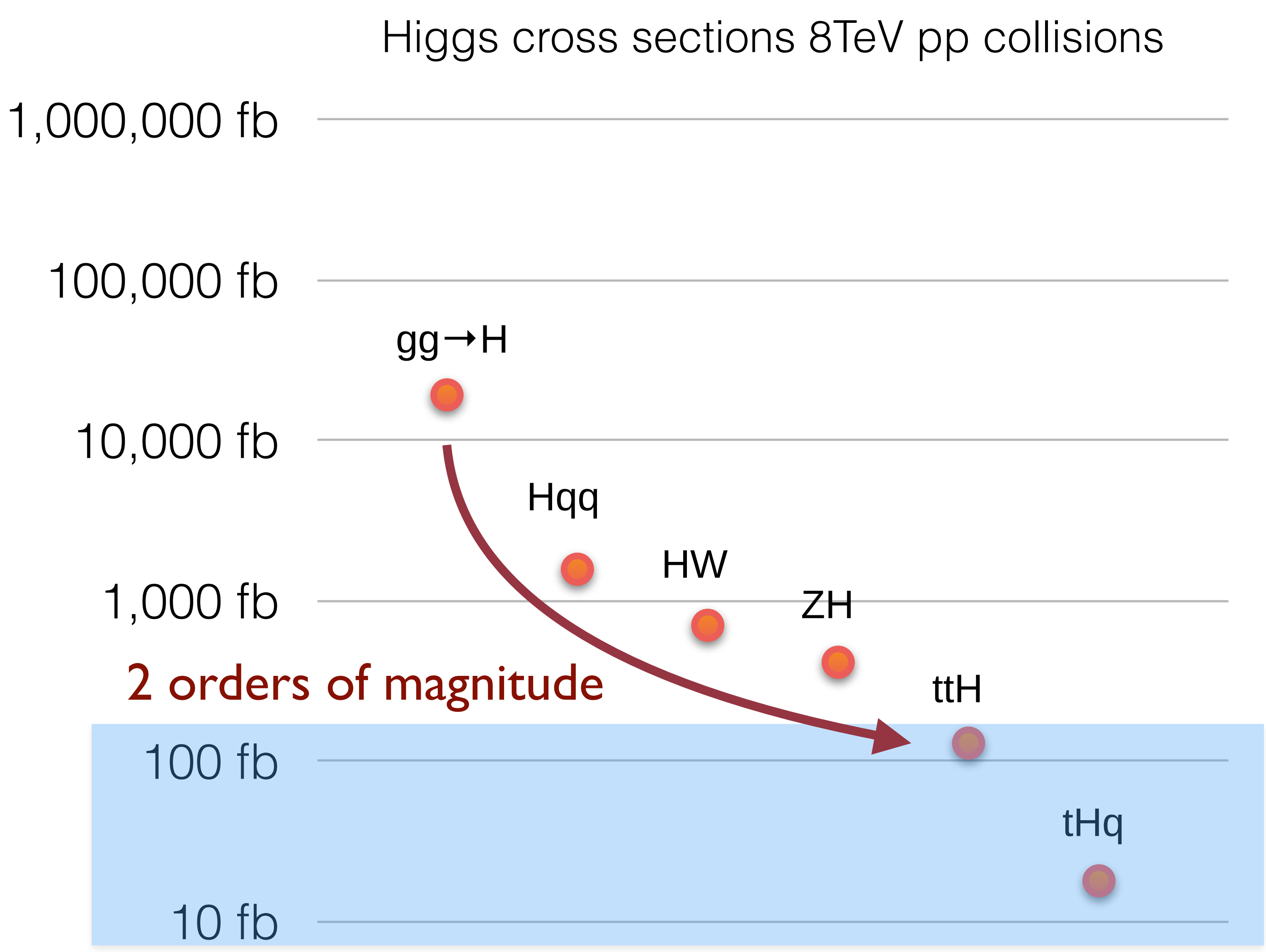

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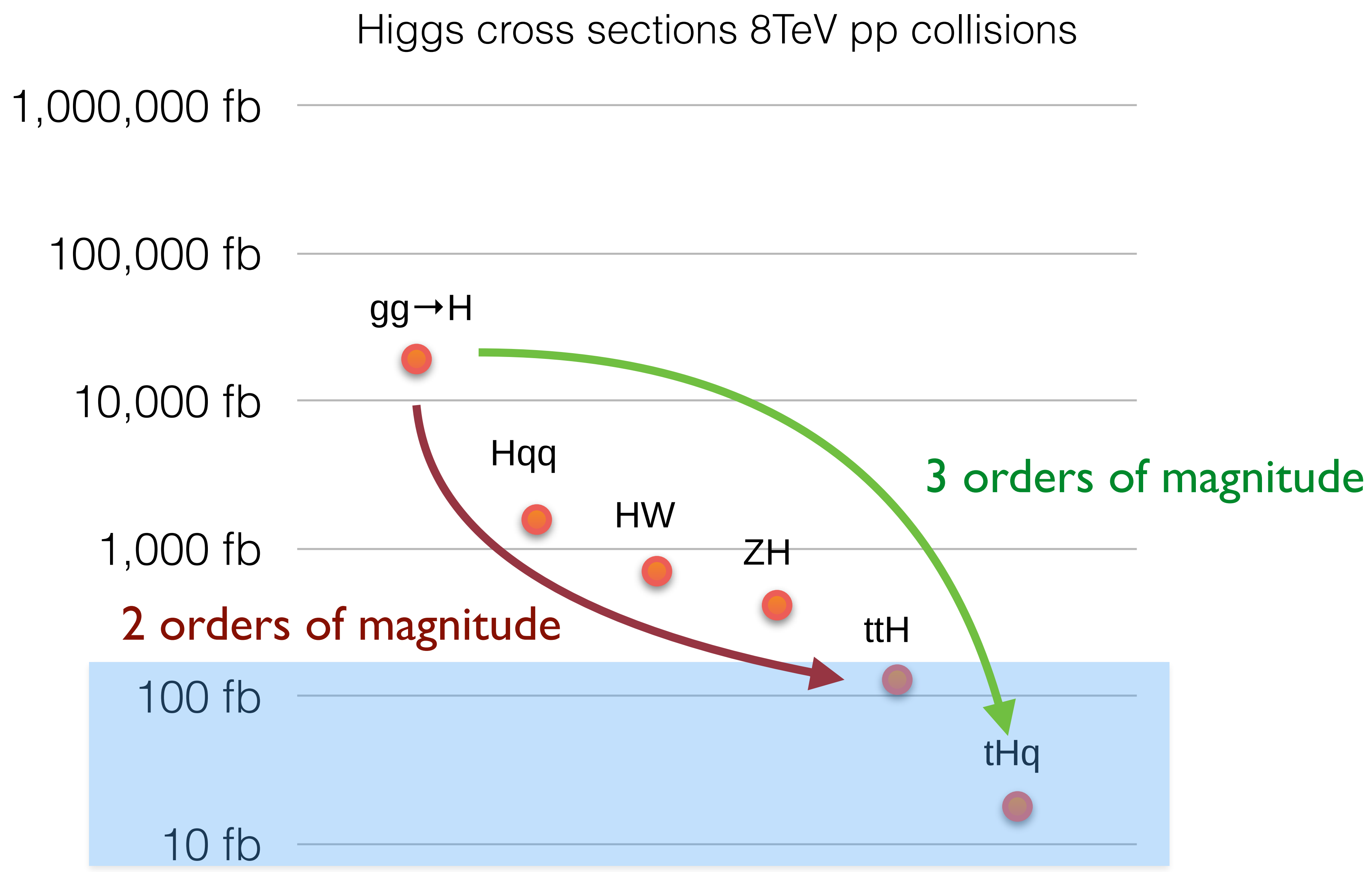
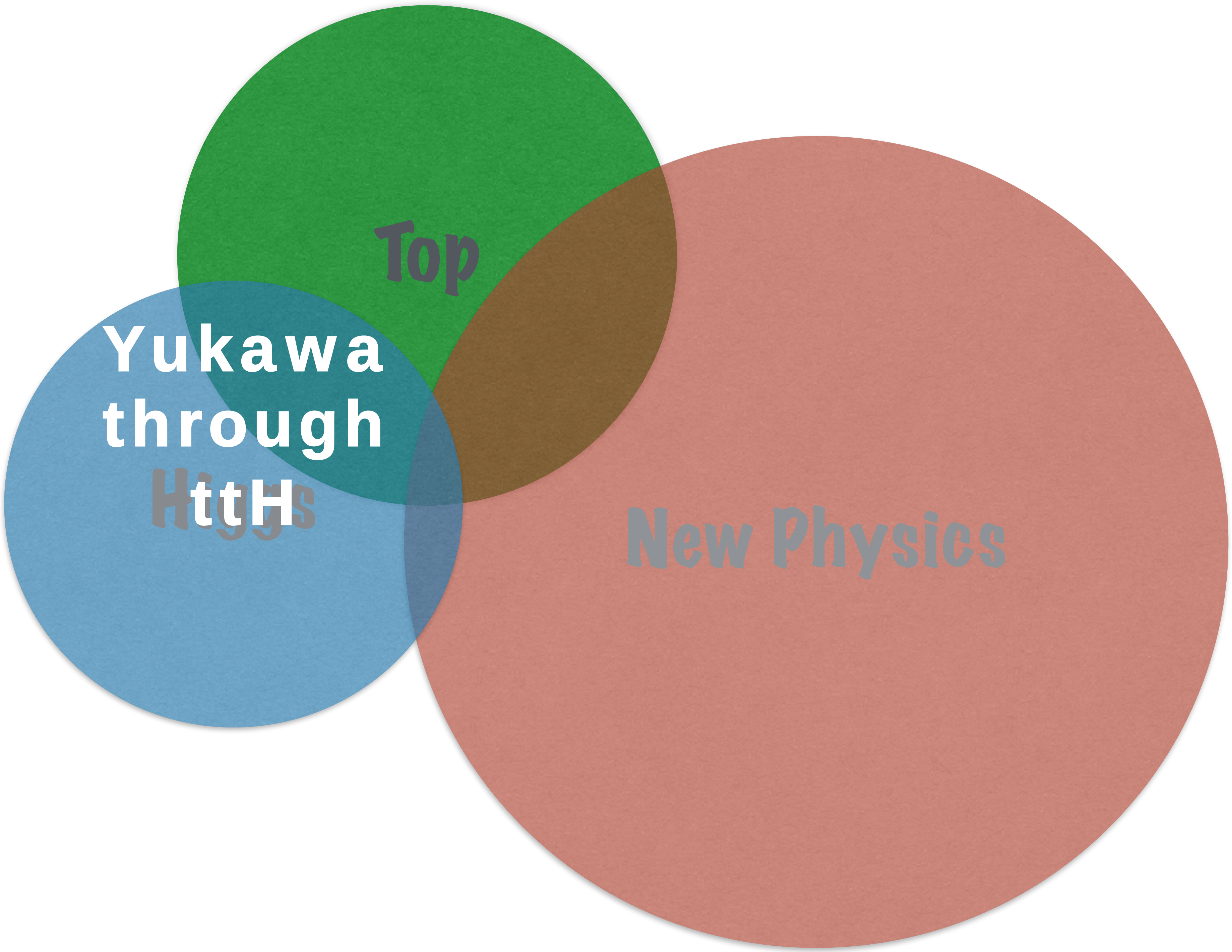
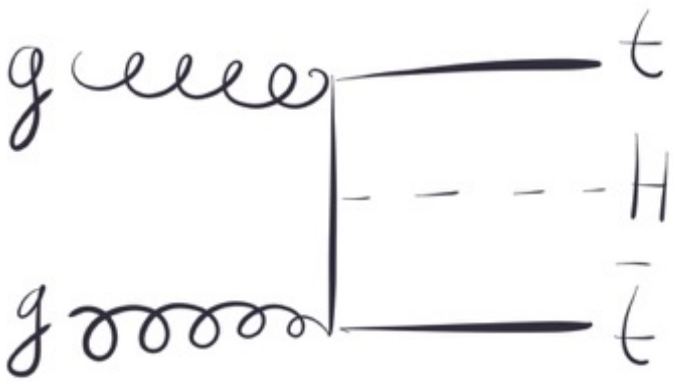



Top
Yukawa
through
ttH
Higgs
New Physics

TTH: *VERY* COMPLEX FINAL STATE

- Cross section is only ~1/200 of the inclusive Higgs production cross section
- Large multiplicity of objects in the final state
  - top quarks decay to Wb, W bosons decay in turn leptonically (lnu) or hadronically (qq)
  - Higgs bosons decay to anything but top quarks…
- Need to find the best combination of top and Higgs decays to isolate the small signal (130fb)



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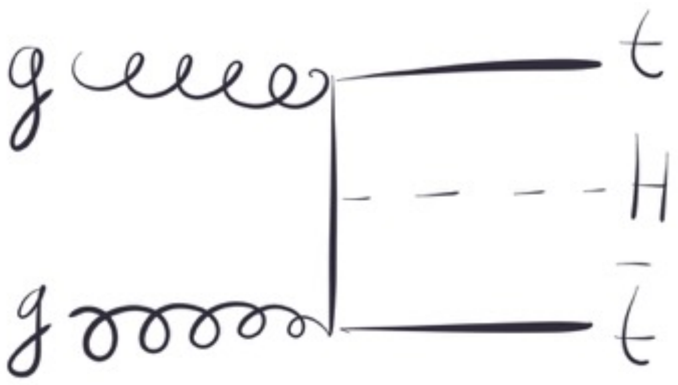
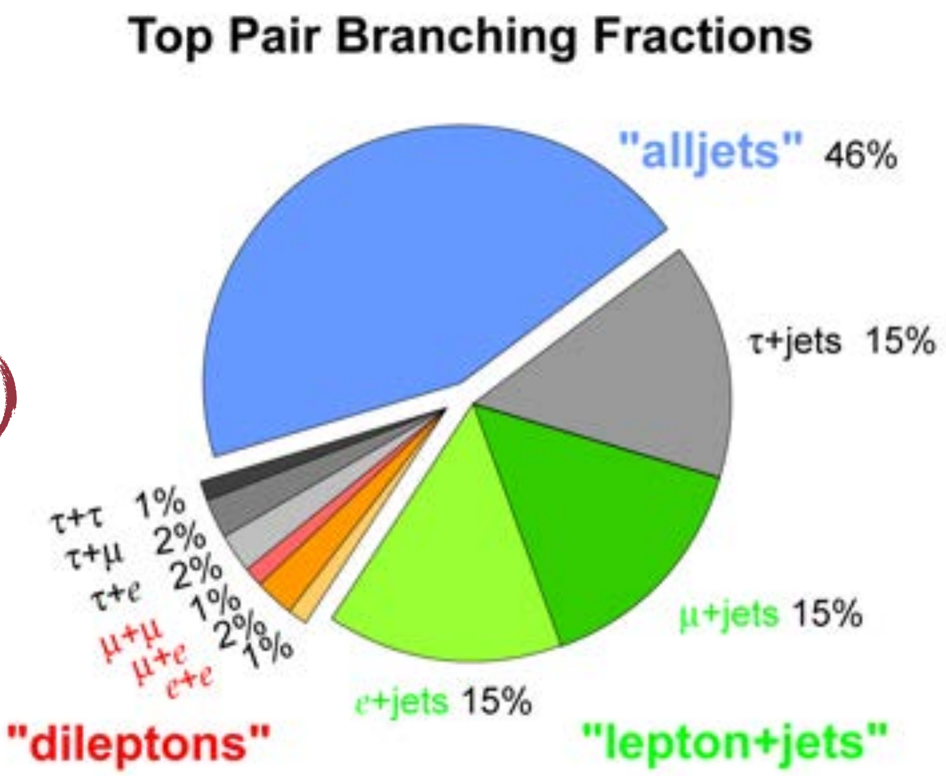


X



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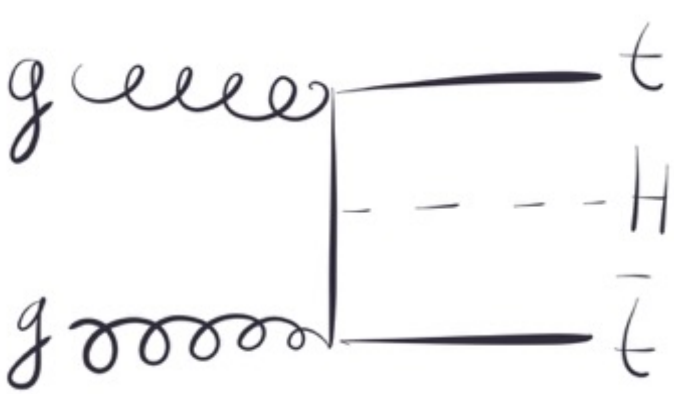
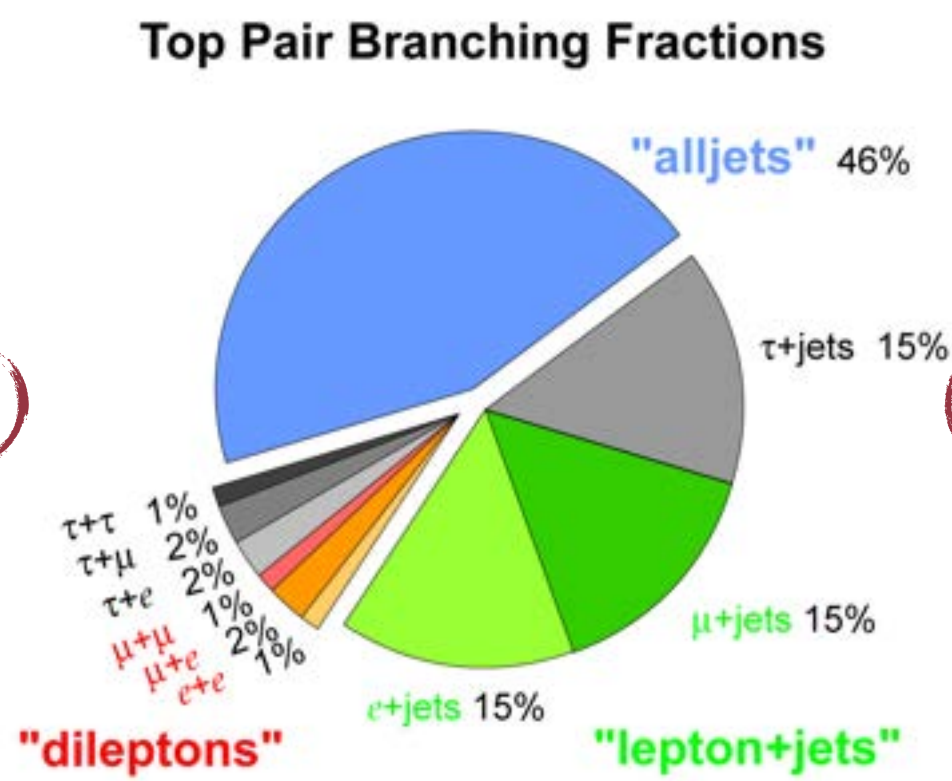
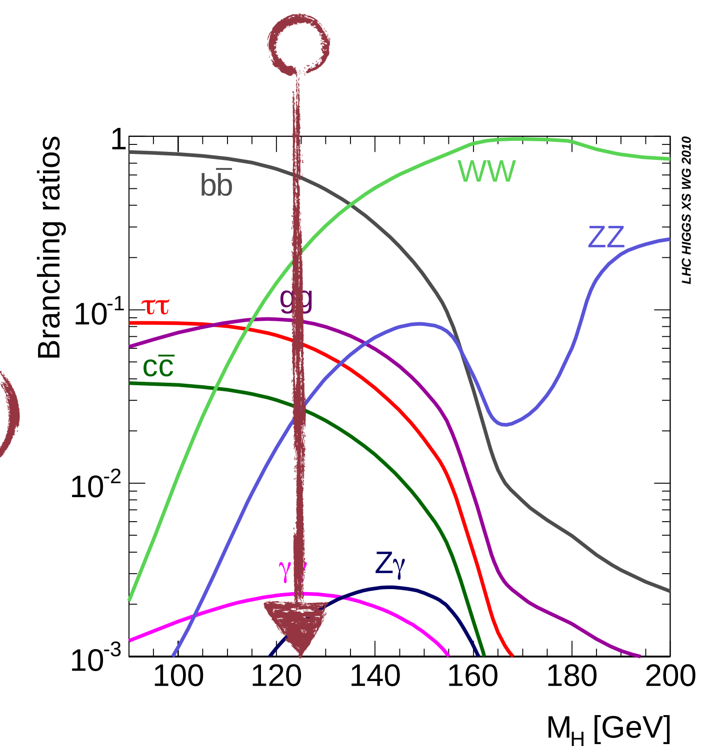


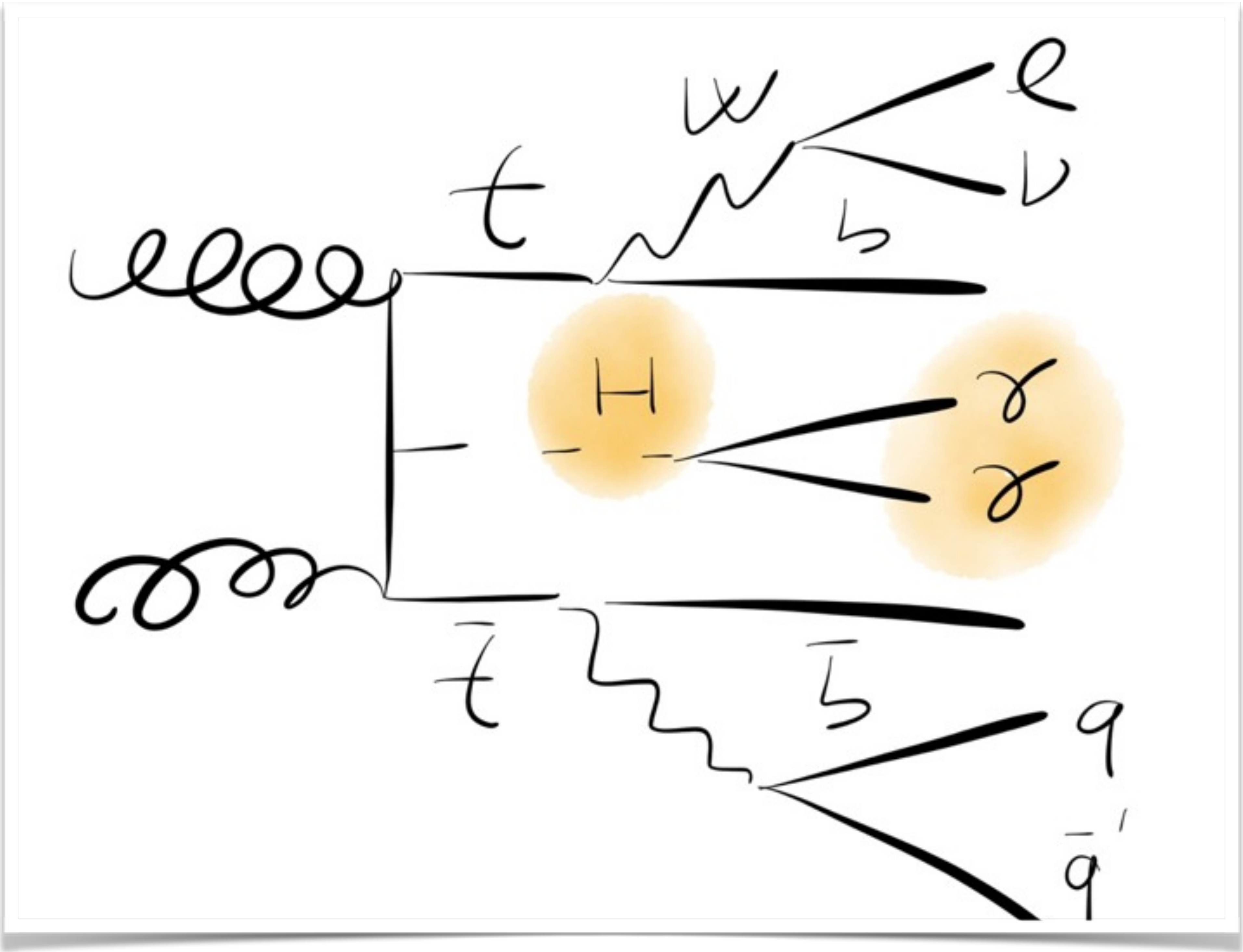
X



X

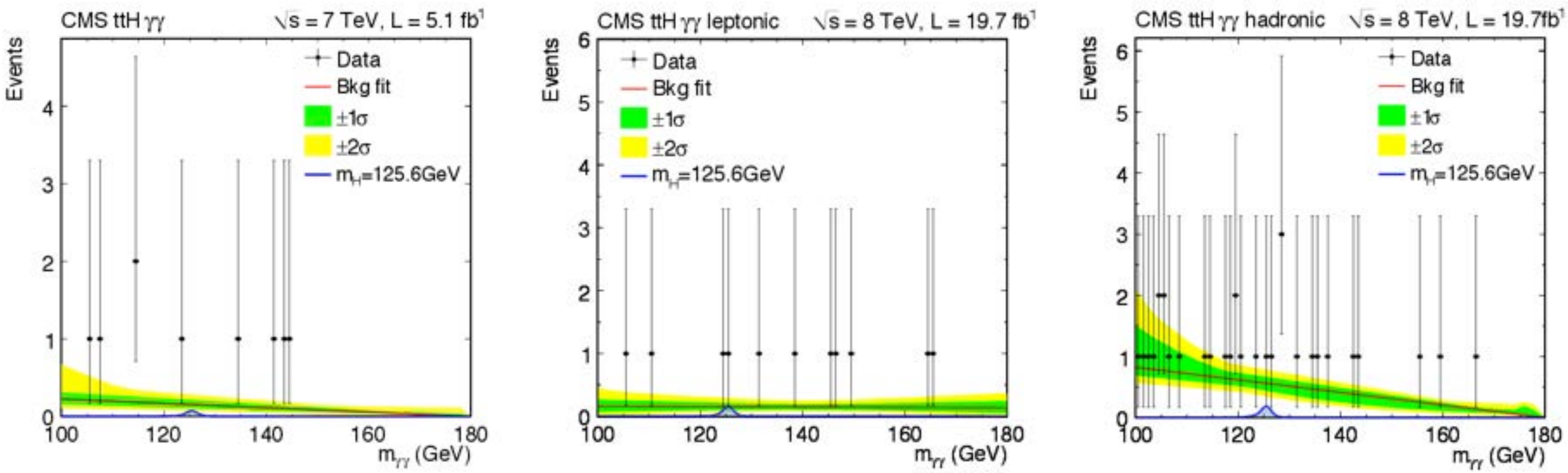


ttH, Higgs to gamma gamma



HIGGS TO GAMMA GAMMA

- Very low rate, but distinctive signature of the Higgs peak. Backgrounds are coming from top(s) +photon(s), or photons+(b)jets, latter poorly known at theoretical level
- Split into events with leptons and few jets (leptonic) or no leptons and many jets (hadronic)

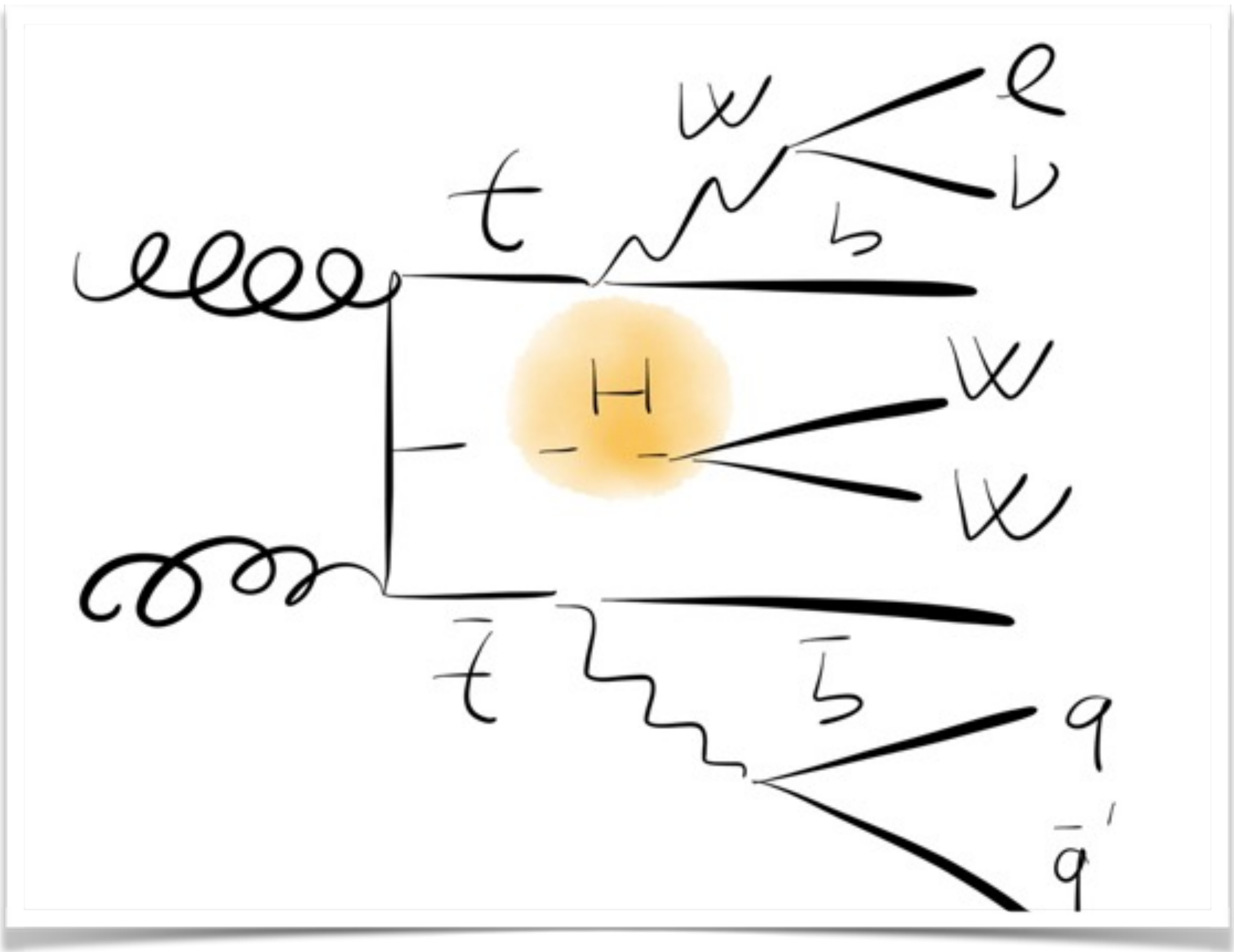


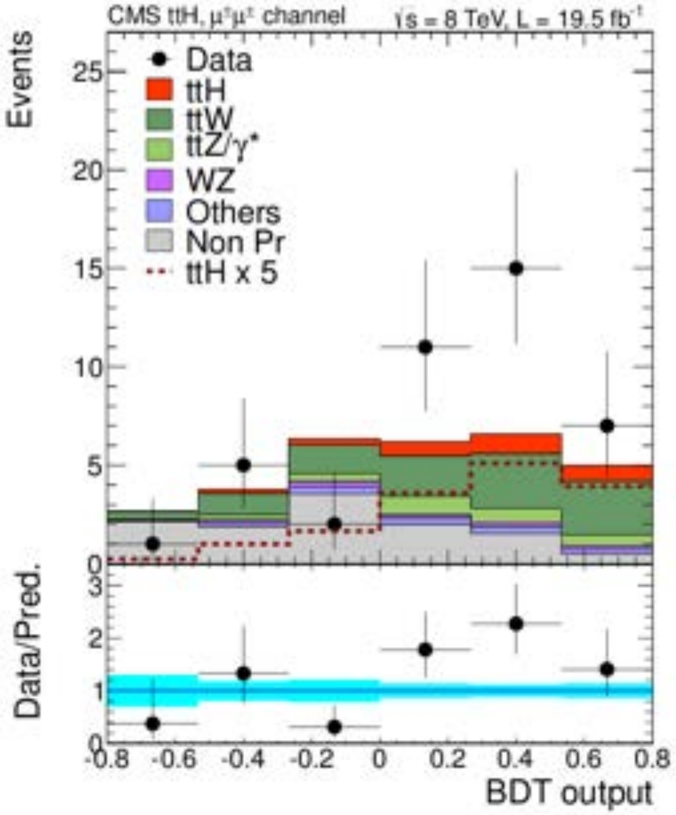
Event selection minimizes contamination from other Higgs sources

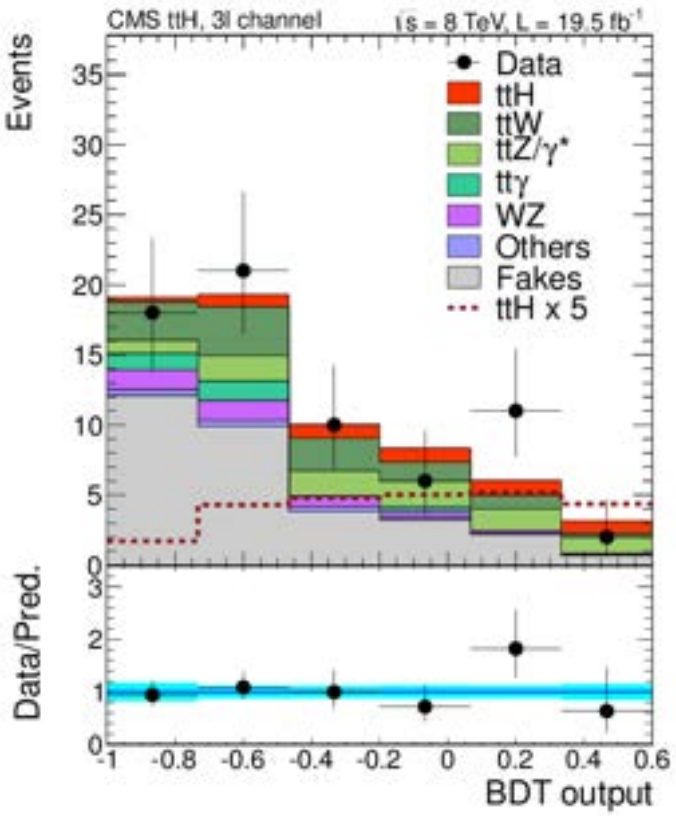
Process	Hadronic Channel	Leptonic Channel
$t\bar{t}H$	0.567 (87%)	0.429 (97%)
$gg \to H$	0.059 (9%)	0 (0%)
VBF H	0.006 (1%)	0 (0%)
WH/ZH	0.019 (3%)	0.013 (3%)
Total signal	0.65	0.44

- fitting the diphoton peak greatly reduce sensitivity to background systematics

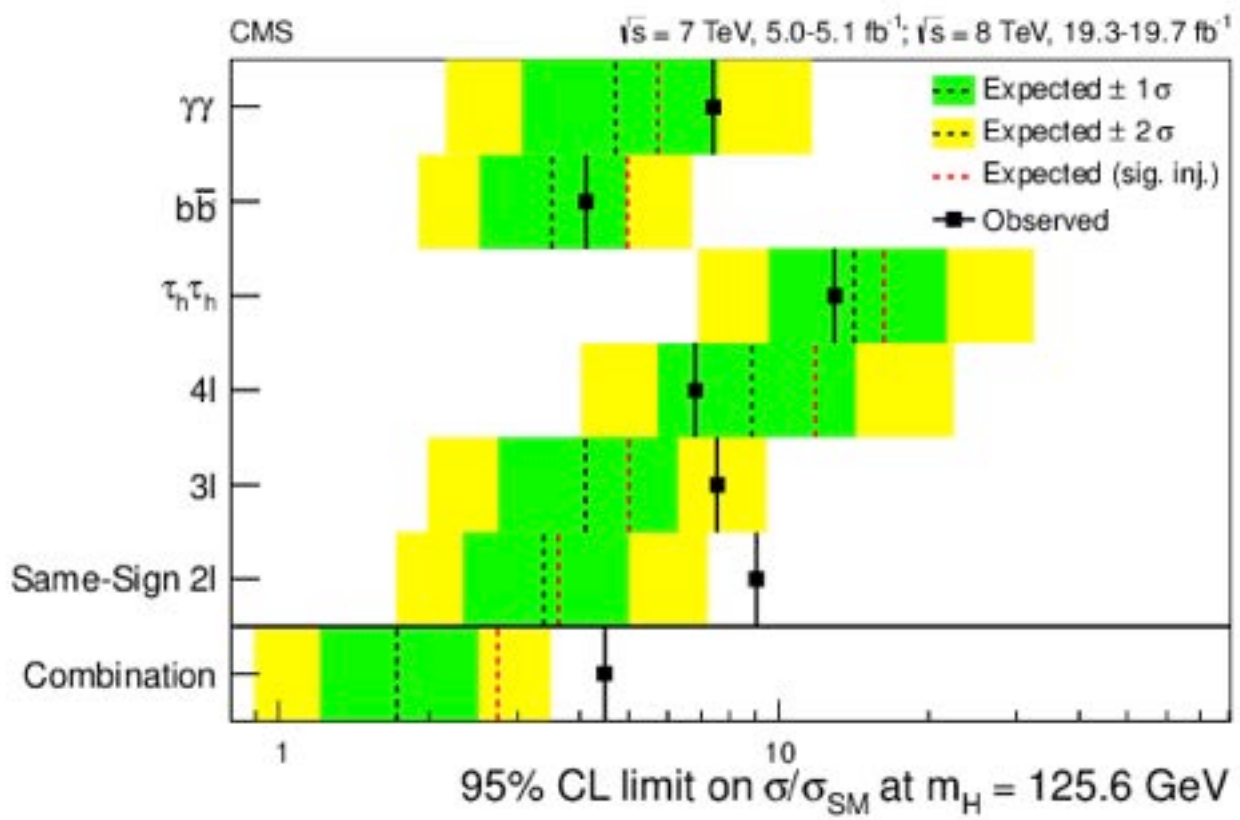
TTH TO MULTILEPTON

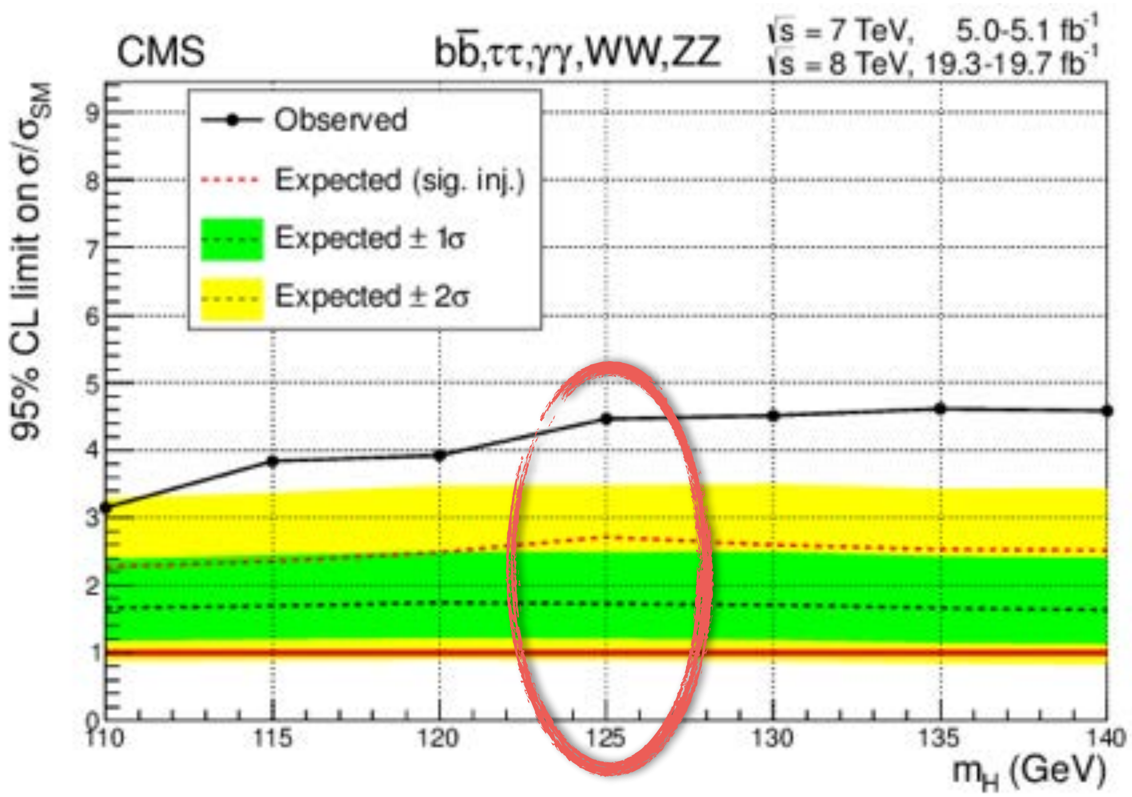






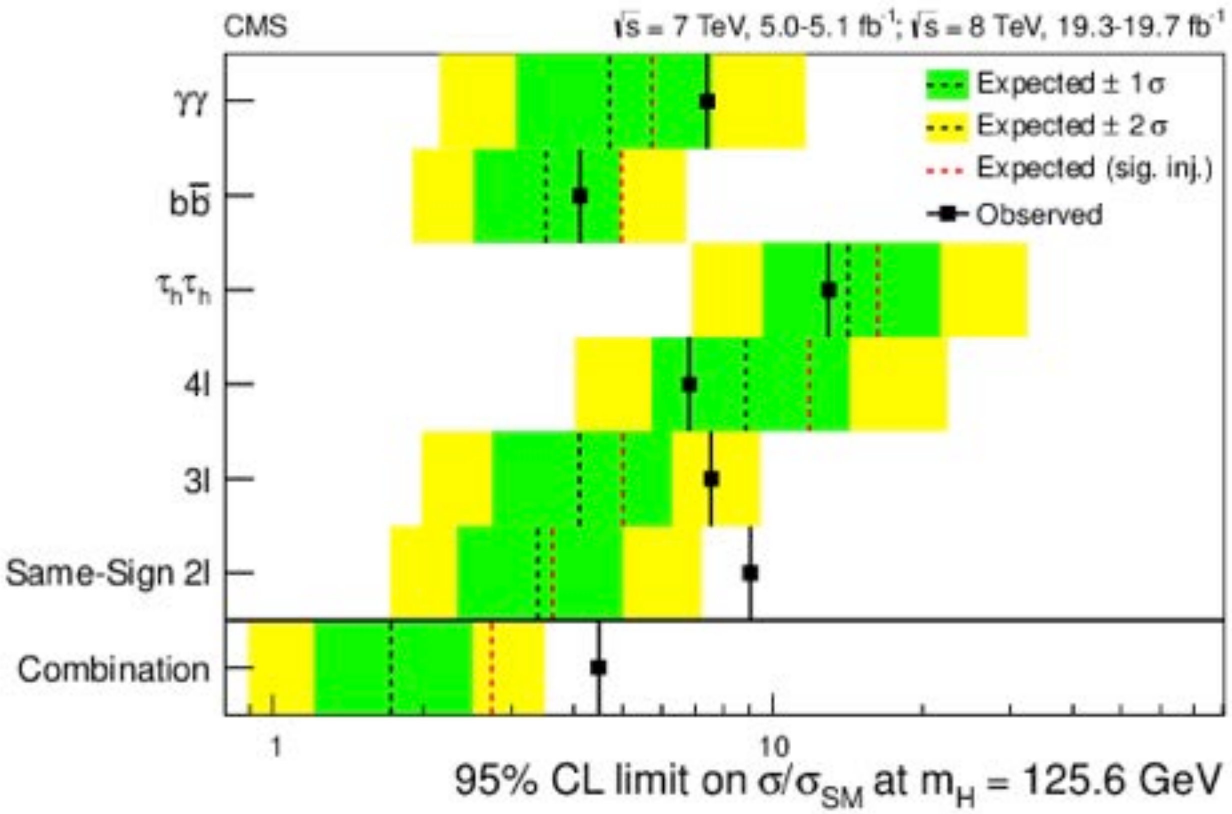
CMS combination on ttH

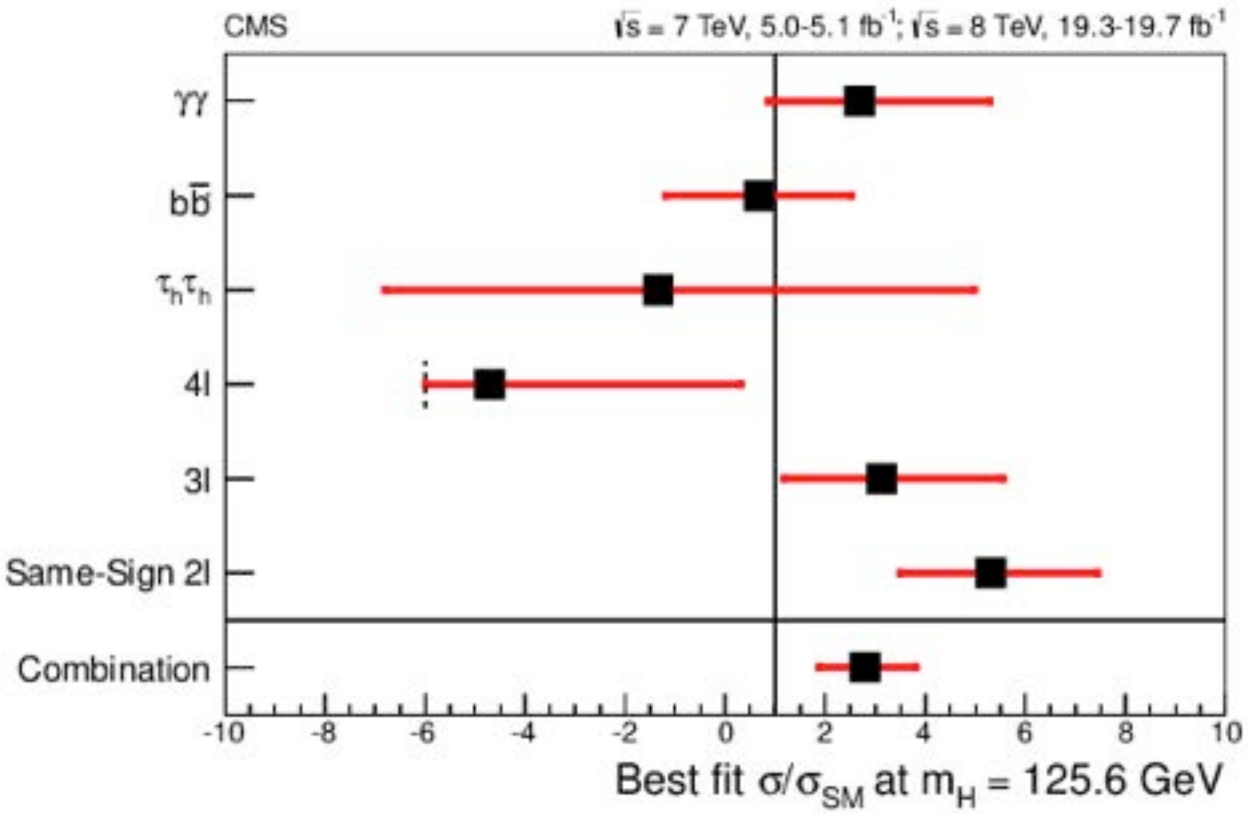


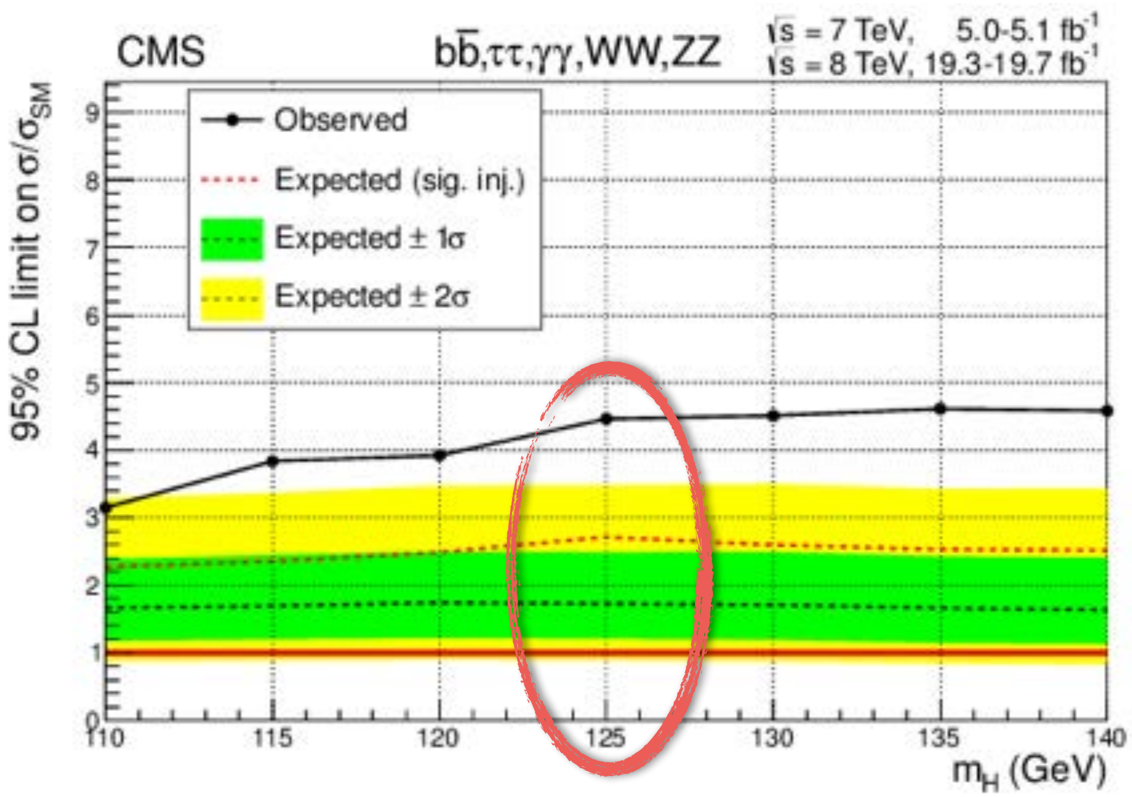


- Set 95% confidence level limits on ttH
- Combined exp(obs) limit of 1.7(4.5) X SM

CMS COMBINATION ON TTH







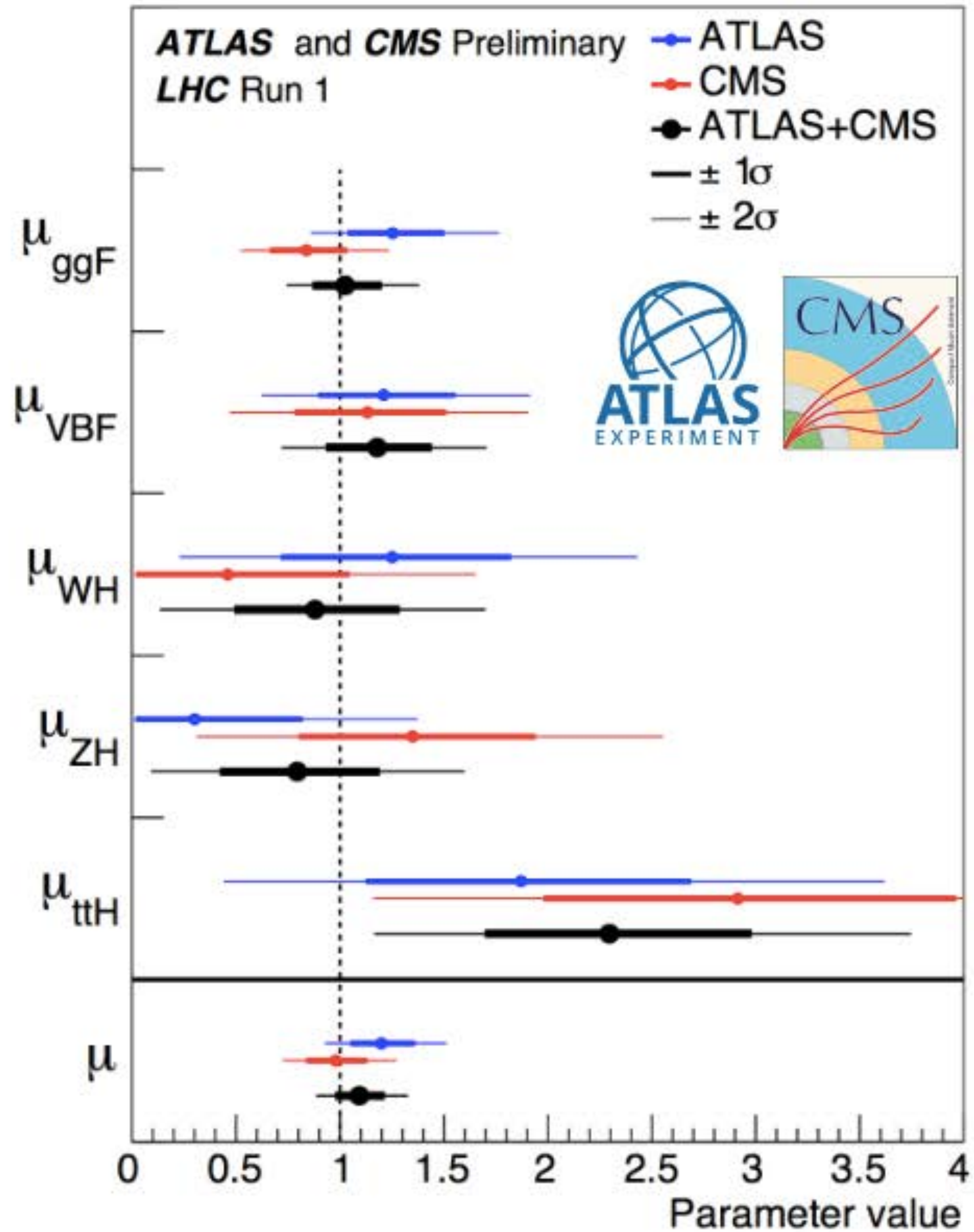
- Set 95% confidence level limits on ttH
- Combined exp(obs) limit of 1.7(4.5) X SM
- Intepreting the result as a cross section measurement
- Combined signal strength multiplier $\mu=2.8^{+1.0}_{-0.9}$ X SM

Global fit to Higgs couplings

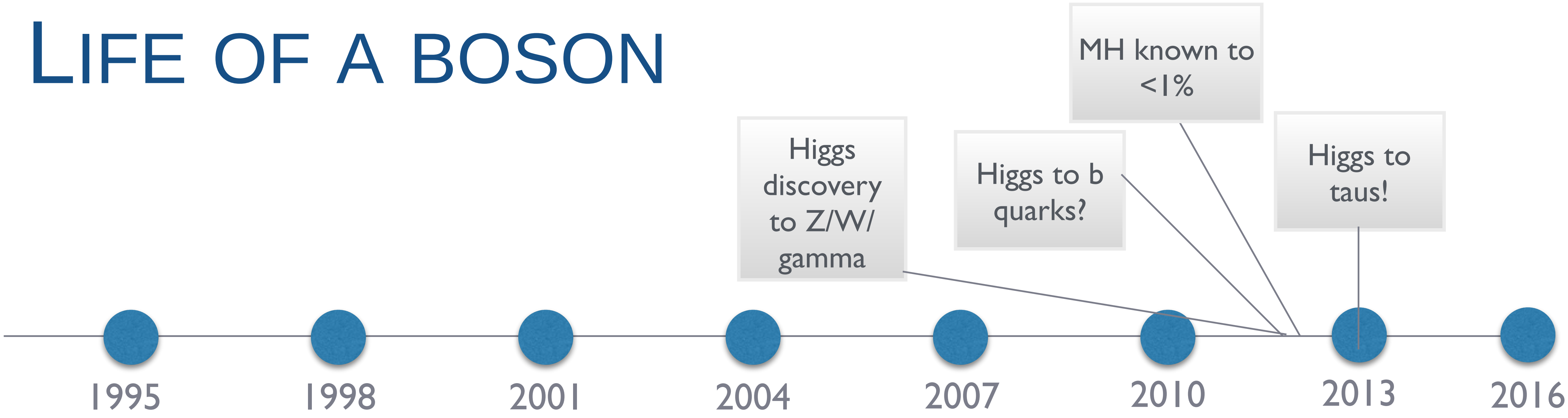
- Recently ATLAS & CMS published the Run-1 combined measurements of the Higgs production and decay rates and constraints on its couplings.

- This includes the combined value for the ttH signal strength:
  - $\mu_{ttH} = 2.3^{+0.7}_{-0.6}$
  - Significance: 4.4σ (2.0σ expected)

- Total combined signal strength:
  - $\mu = 1.09^{+0.11}_{-0.10}$



LIFE OF A BOSON



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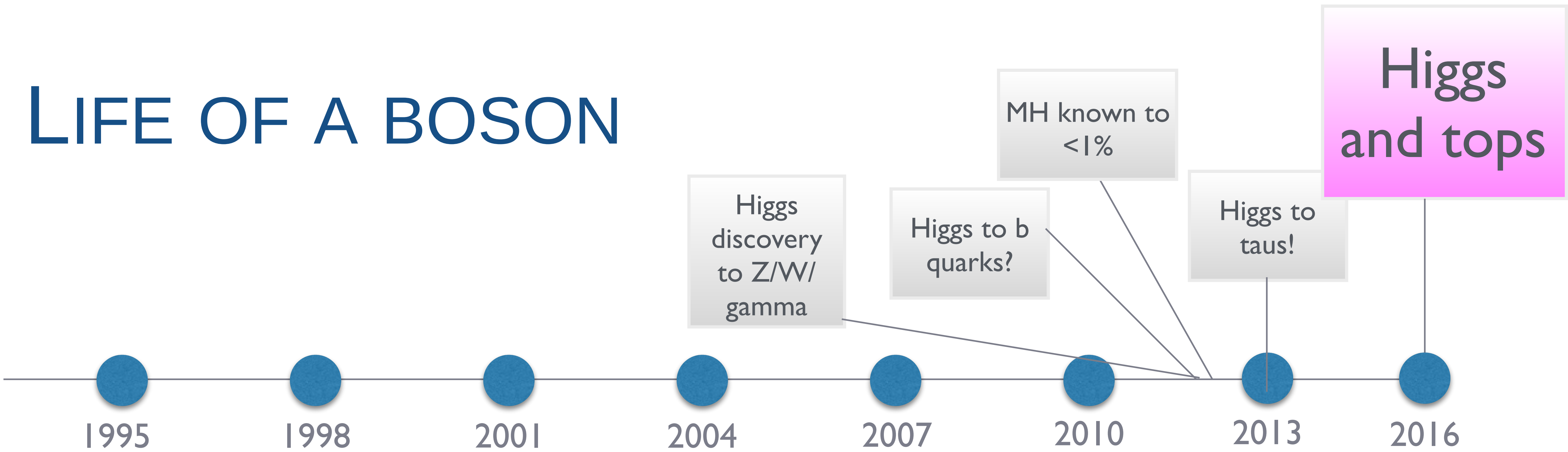
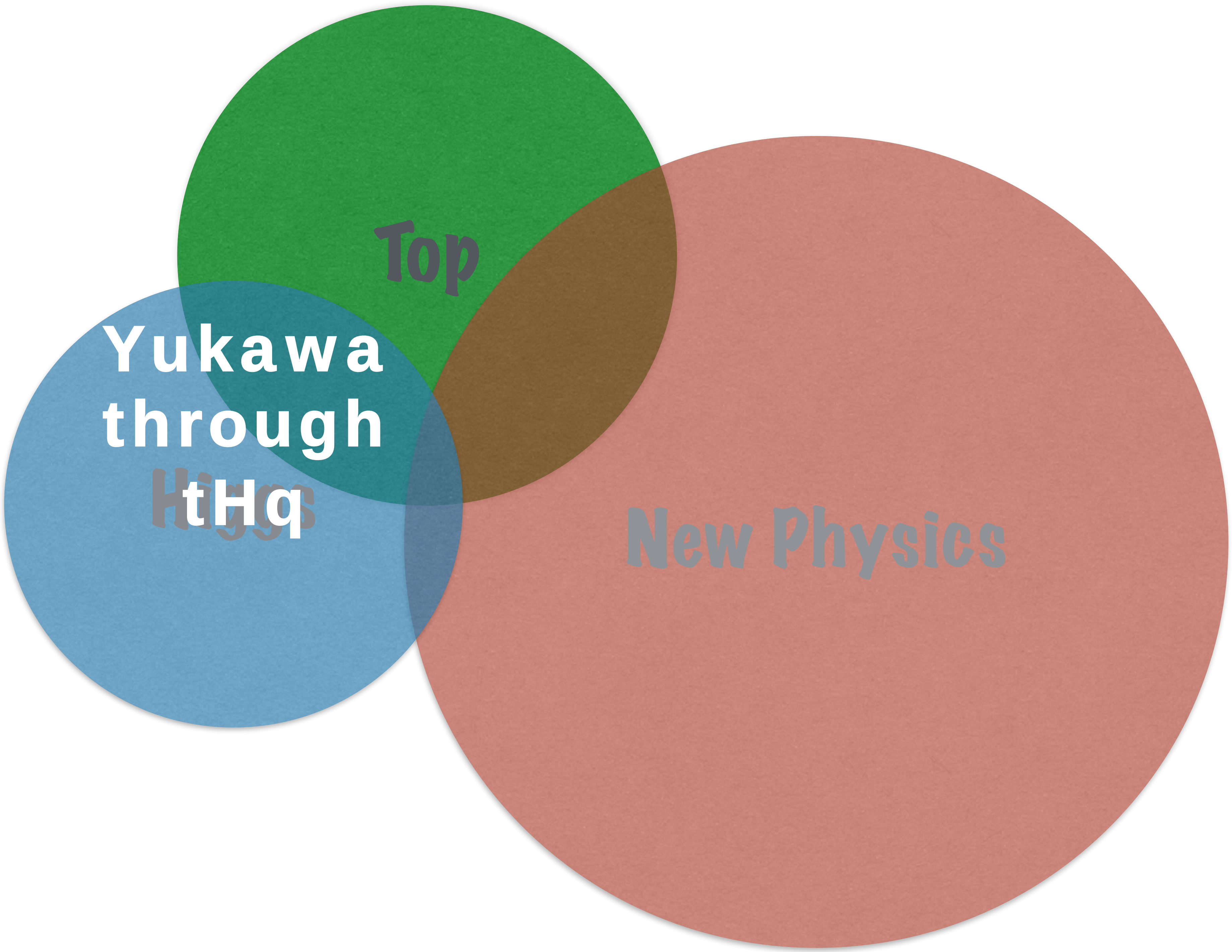
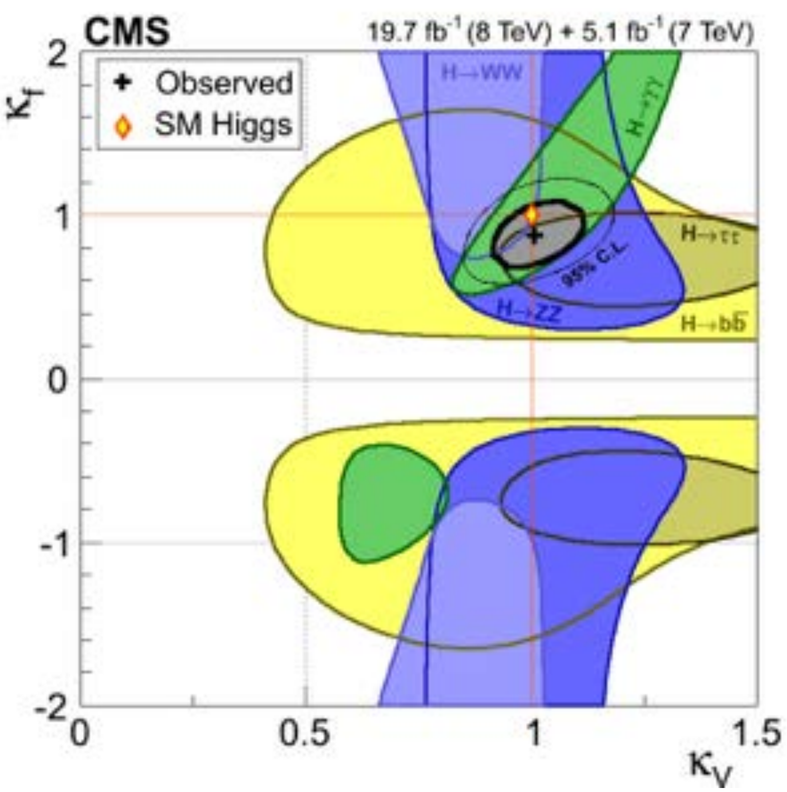


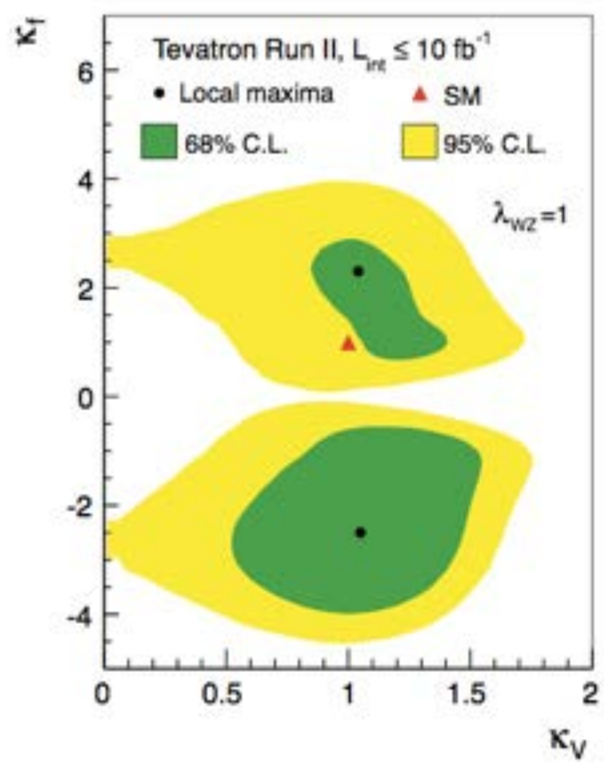
LHC in 2016 will reach sensitivity to Y_t forecasted in the CMS physics TDR for 300fb-1 of 14TeV LHC (~2022)

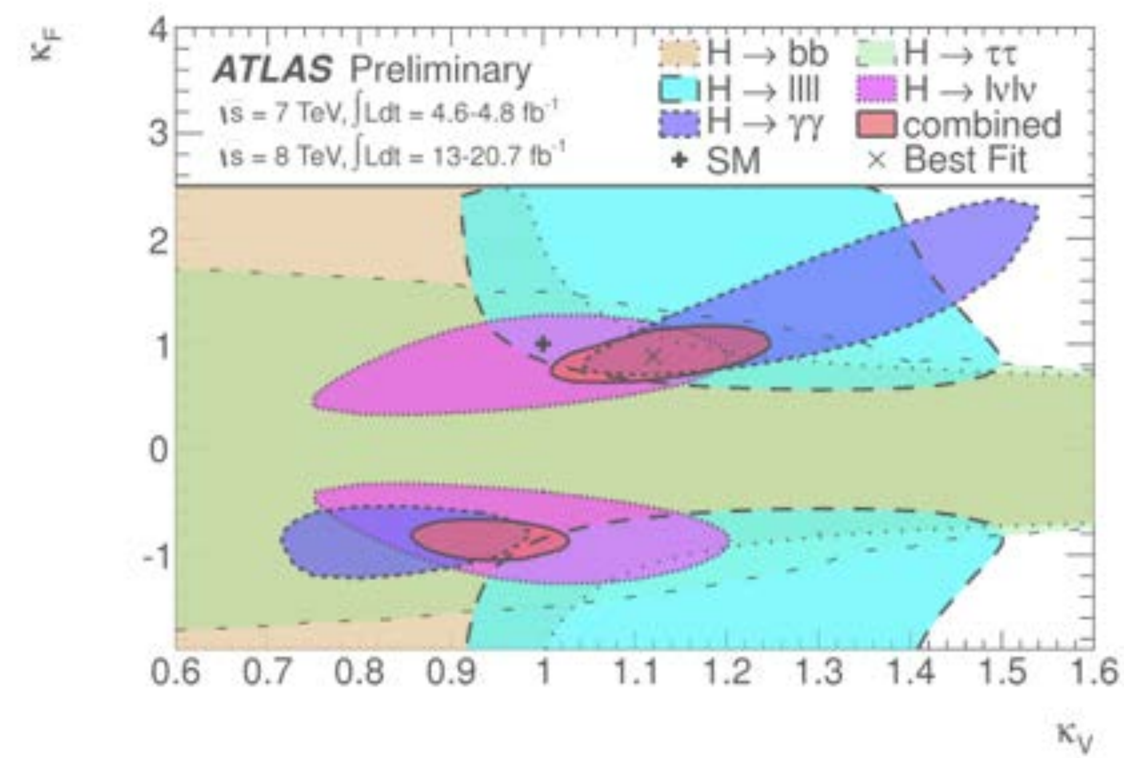

Top
Yukawa
through
tHq
Higgs
New Physics

SINGLE TOP PLUS HIGGS

- Early Higgs data allowed inverted sign of the coupling of Higgs to fermions, relative to Higgs to bosons, hence ambiguity about the kind of interference (+ or -) between Htt and HWW in the Higgs to diphoton decay
- Single top plus Higgs production would be severely enhanced if that was the case







- t-channel tHq production especially sensitive to sign of Yukawa coupling, as it would bring large enhancement in cross section (x10-20, would exceed ttH production)
- single top plus Higgs would be sensitive to other new physics greatly enhancing its rates:
  - non-diagonal Yukawa/new physics in tHu/tHc flavor-changing-neutral-currents
  - single heavy quark production as in Composite Higgs/Extra dimensions theories

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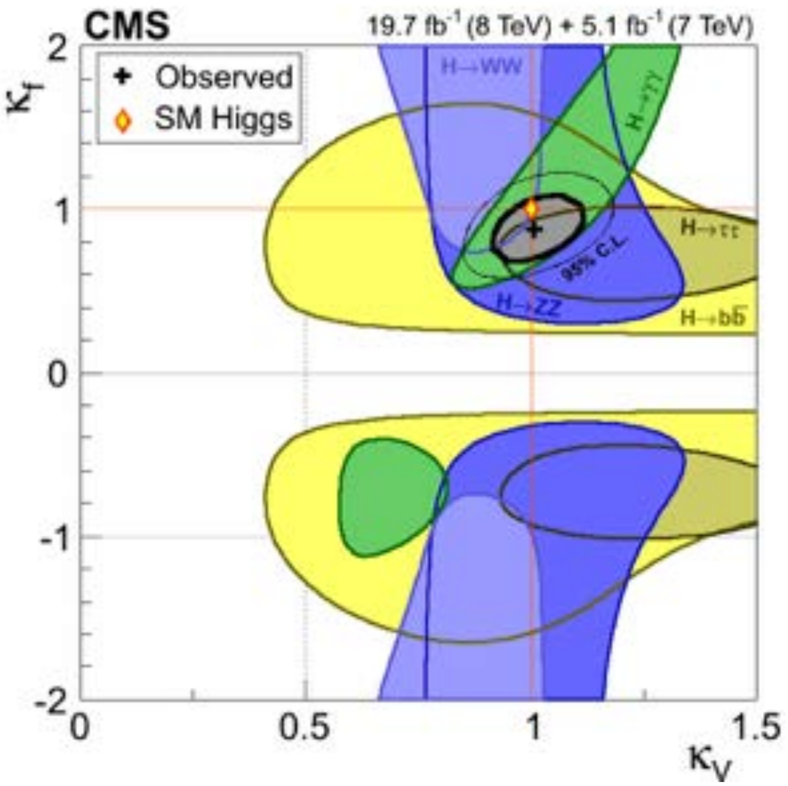
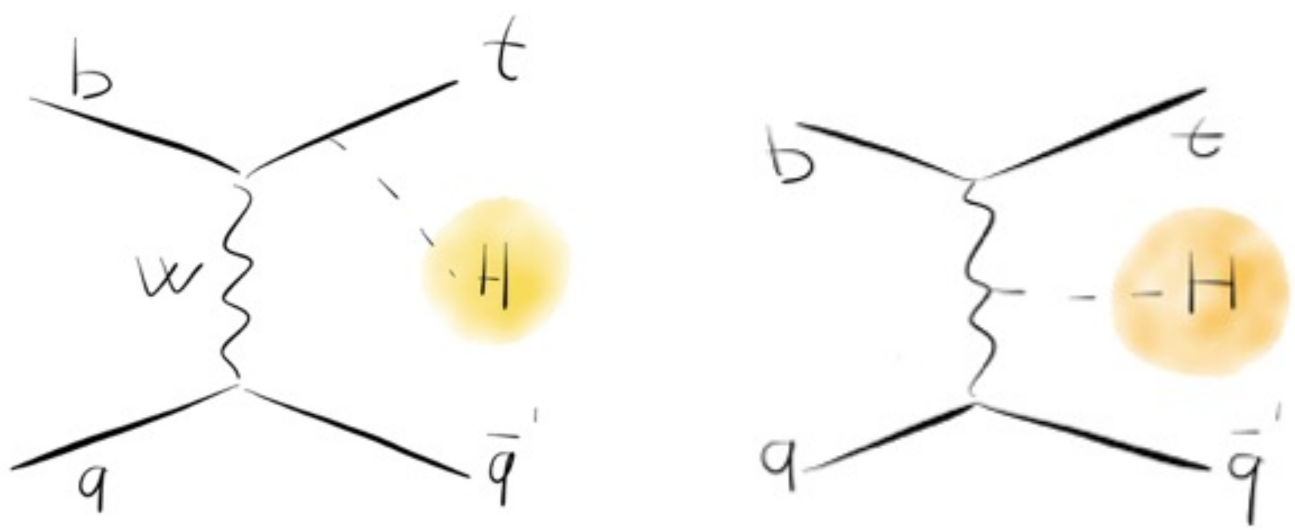
- Early Higgs data allowed inverted sign of the coupling of Higgs to fermions, relative to Higgs to bosons, hence ambiguity about the kind of interference (+ or -) between Htt and HWW in the Higgs to diphoton decay
- Single top plus Higgs production would be severely enhanced if that was the case

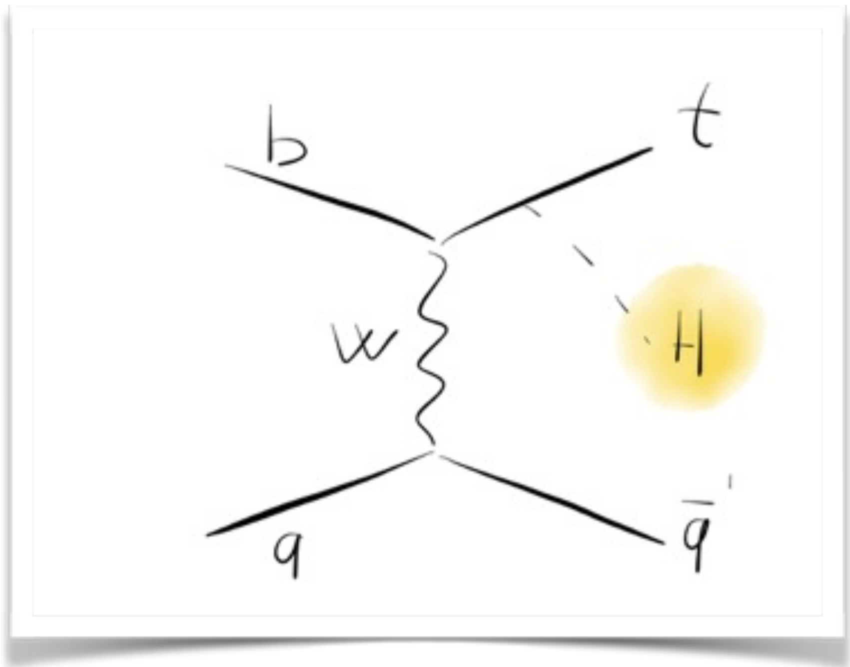


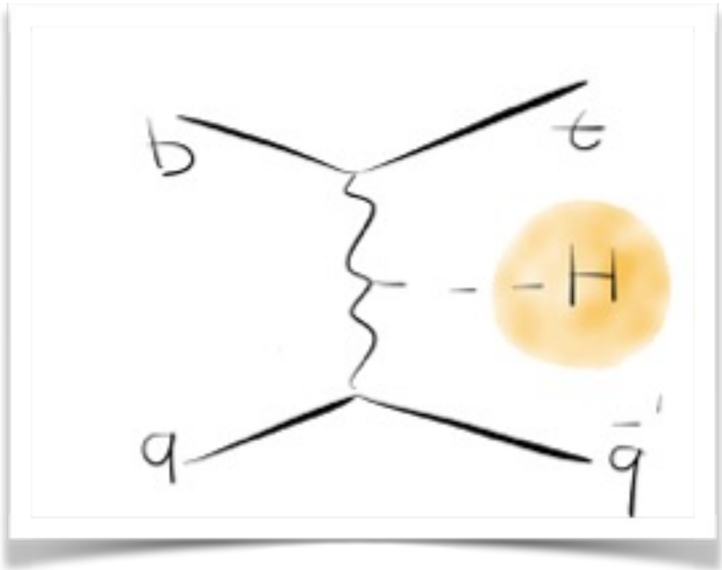


- t-channel tHq production especially sensitive to sign of Yukawa coupling, as it would bring large enhancement in cross section (x10-20, would exceed ttH production)
- single top plus Higgs would be sensitive to other new physics greatly enhancing its rates:
  - non-diagonal Yukawa/new physics in tHu/tHc flavor-changing-neutral-currents
  - single heavy quark production as in Composite Higgs/Extra dimensions theories

Single top plus Higgs

- Measurement of this production mode would probe ttH/WWH interference
  - same kind of interference that bring current Higgs data to allow negative coupling of Higgs to fermions





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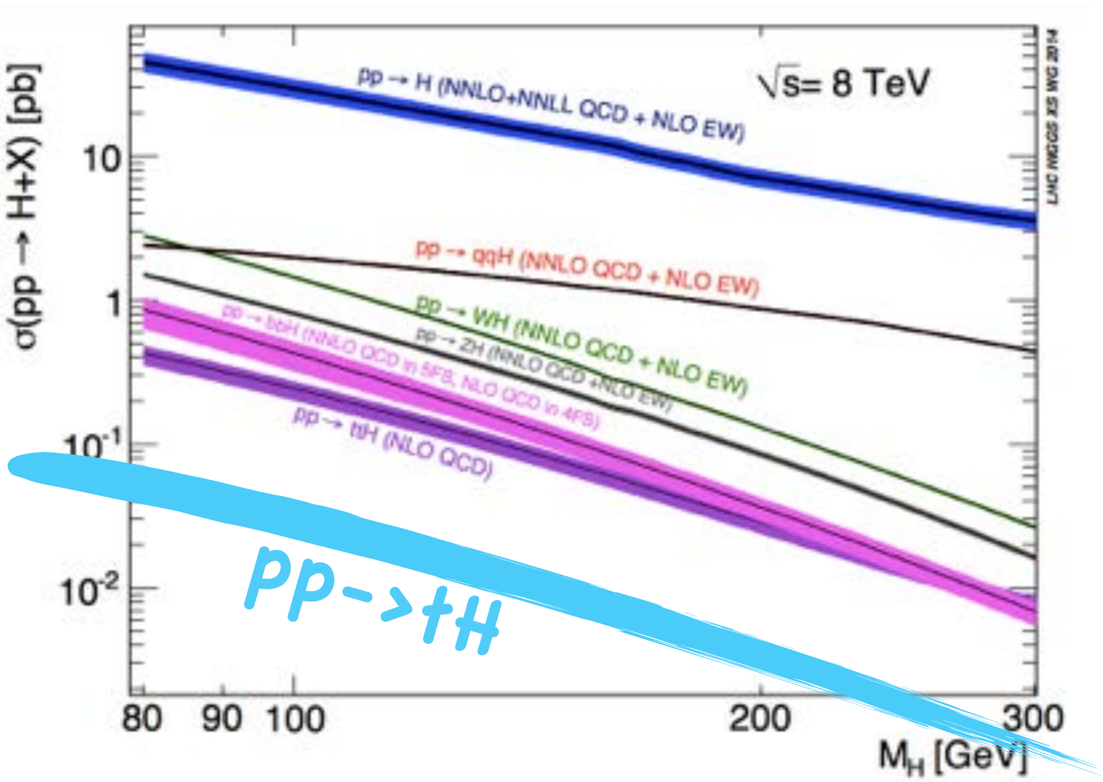
Biswas,Gabrielli,Mele JHEP 01 (2013) 088
Farina,Grojean,Maltoni,Salvioni,Thamm JHEP 05 (2013) 022

SINGLE TOP PLUS HIGGS



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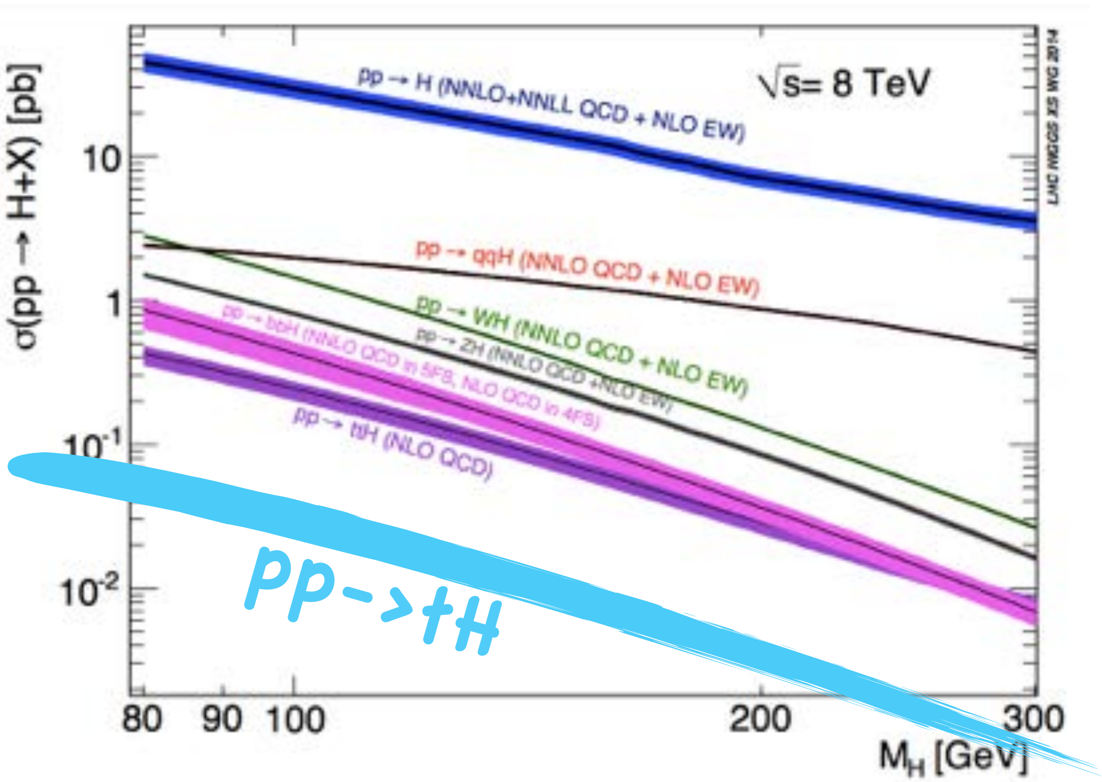

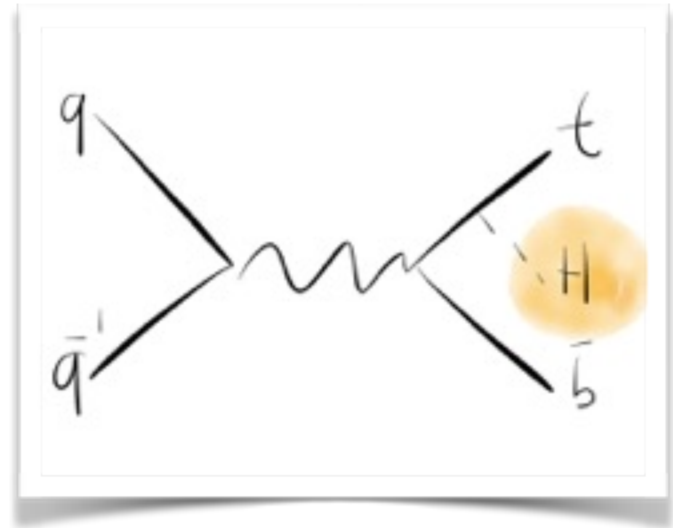

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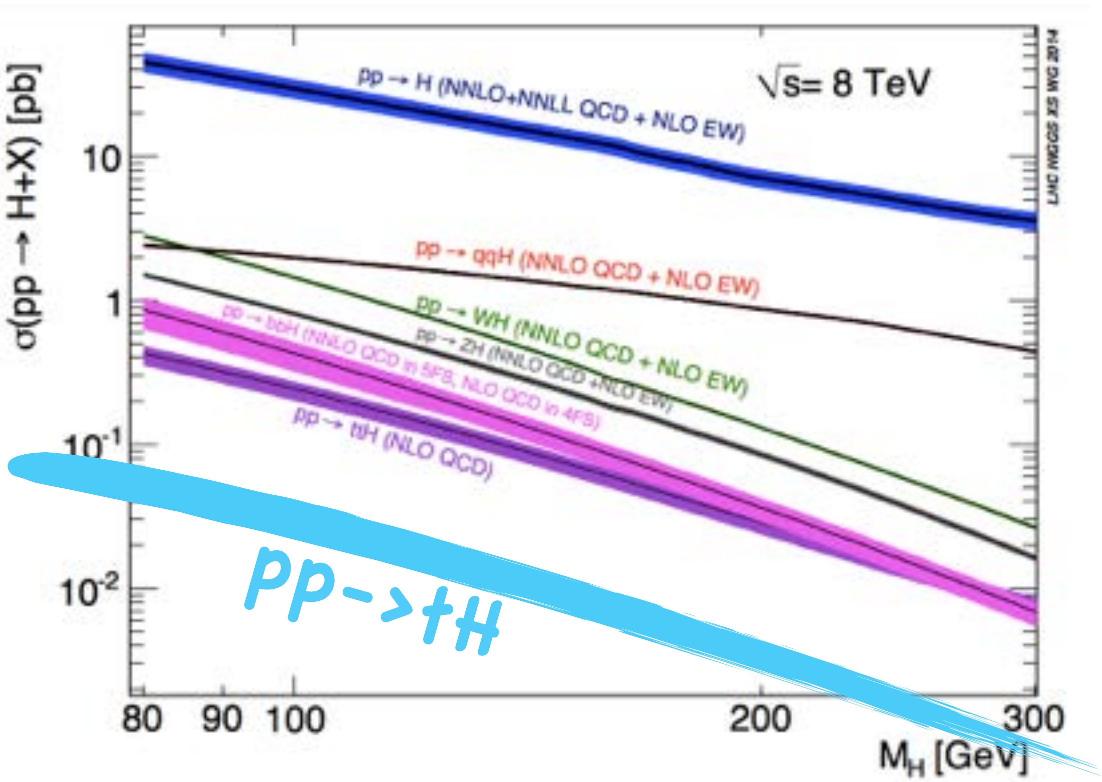

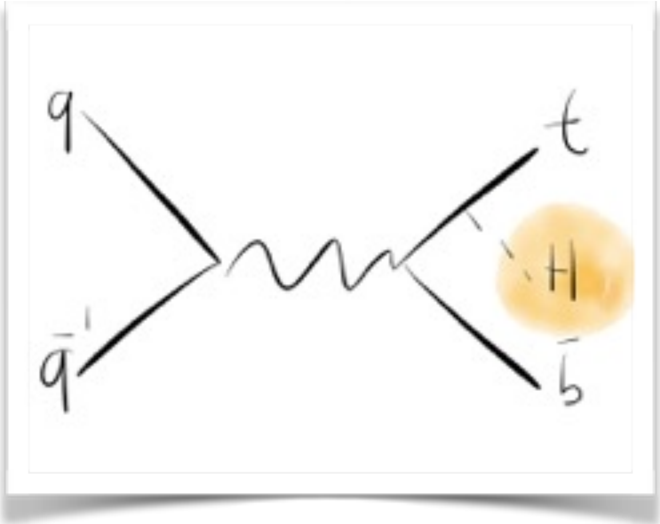

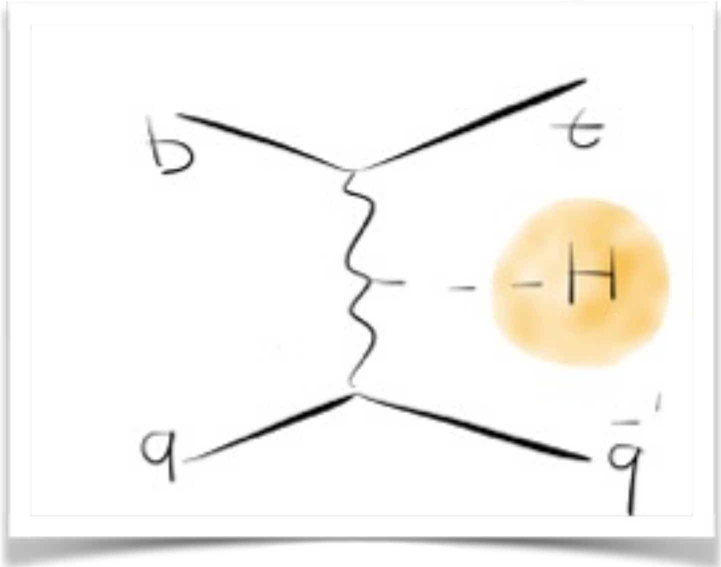

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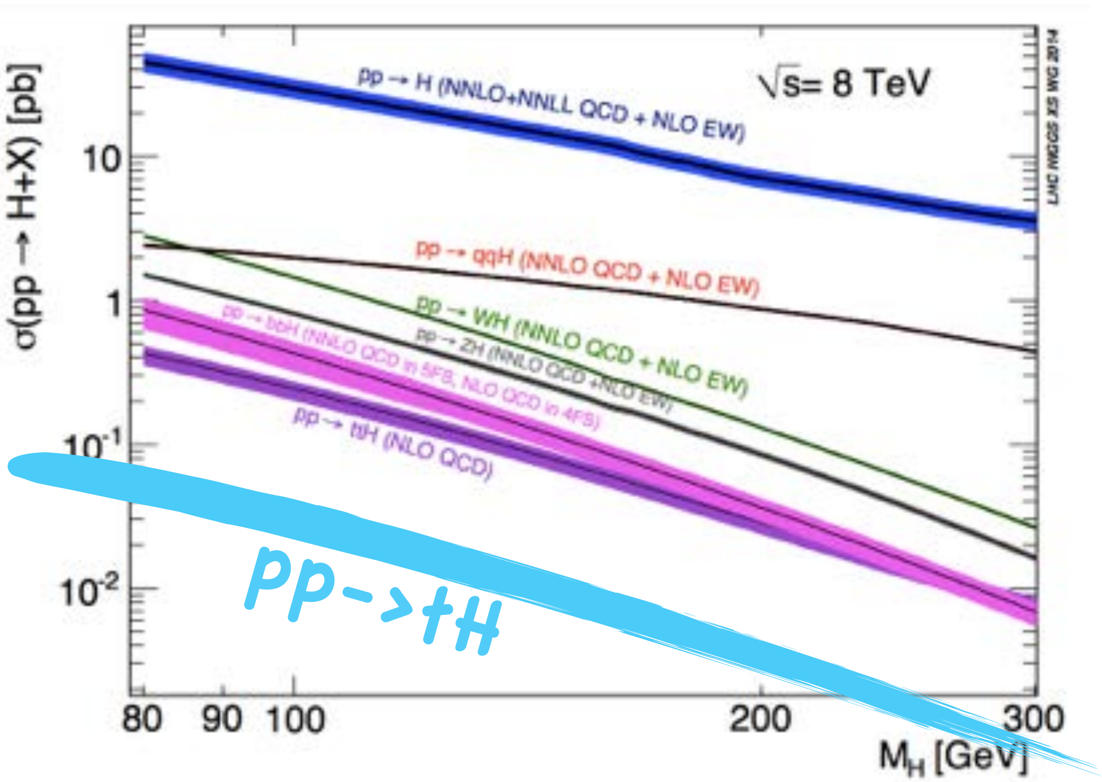
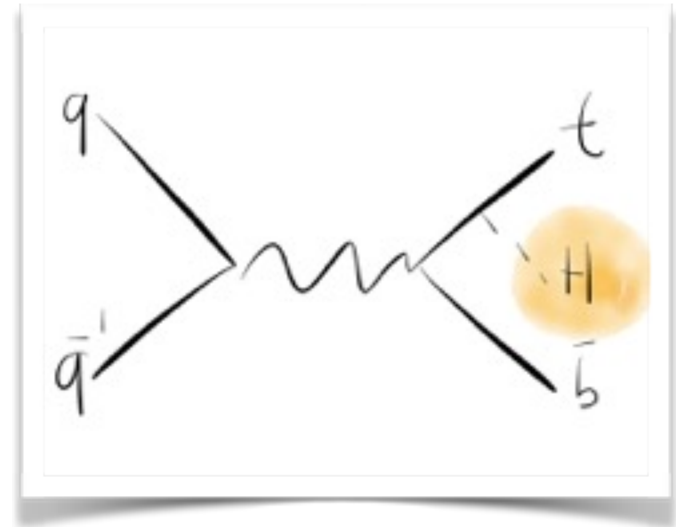
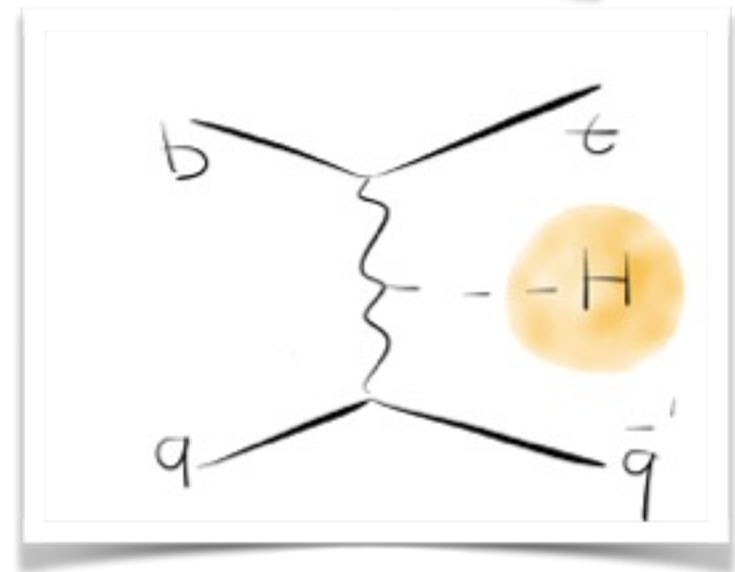
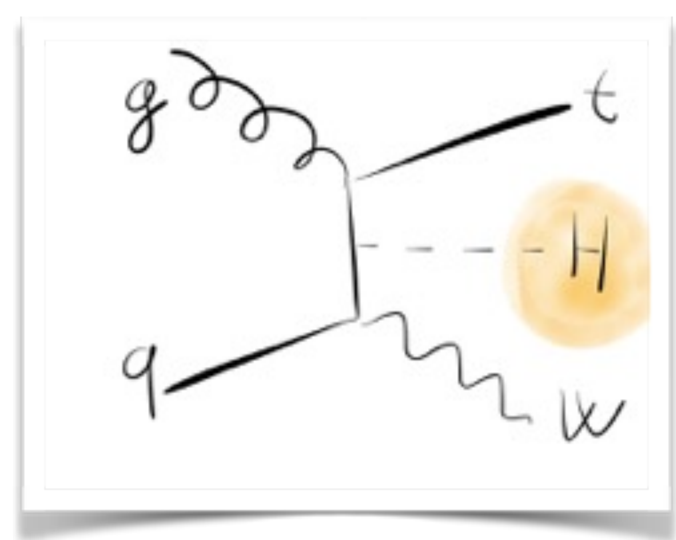
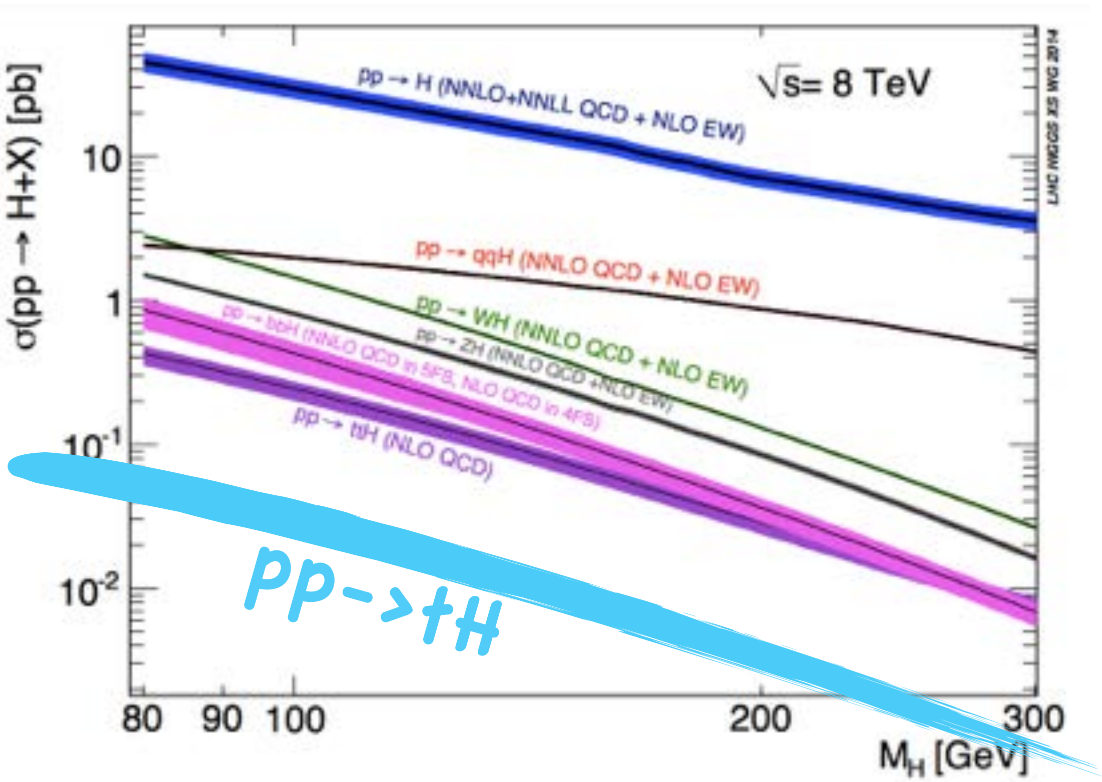


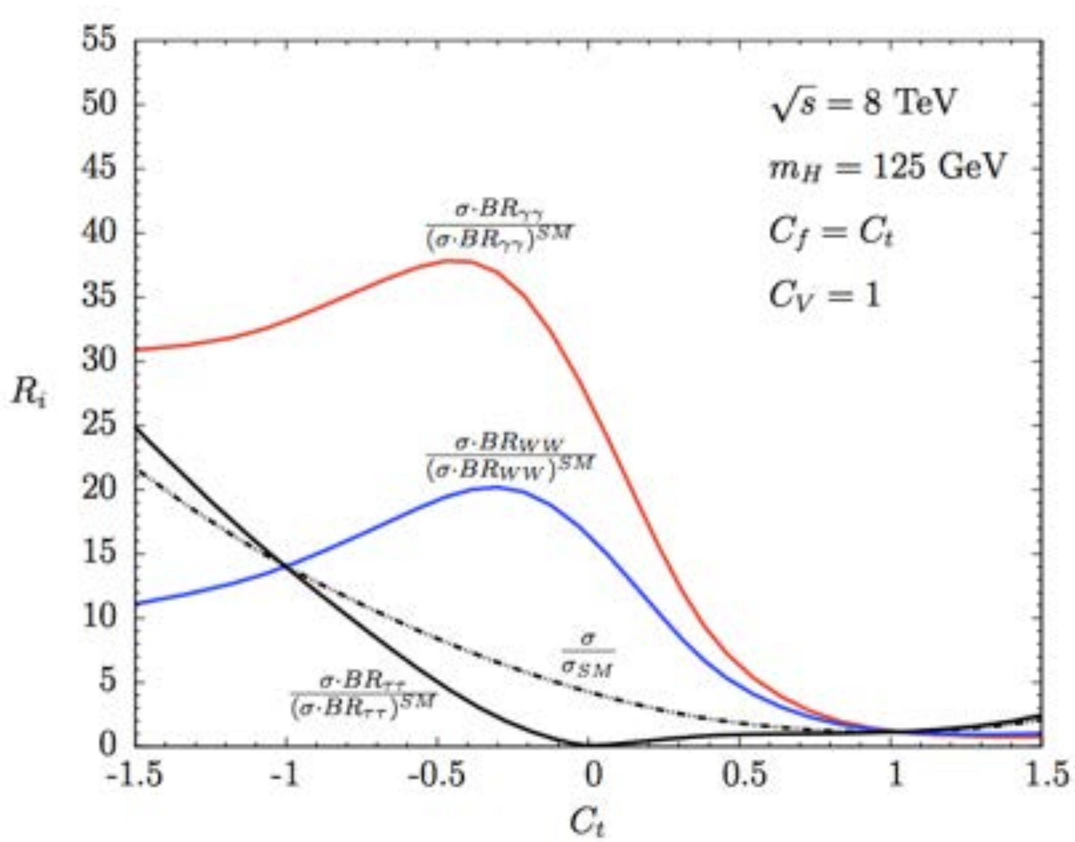


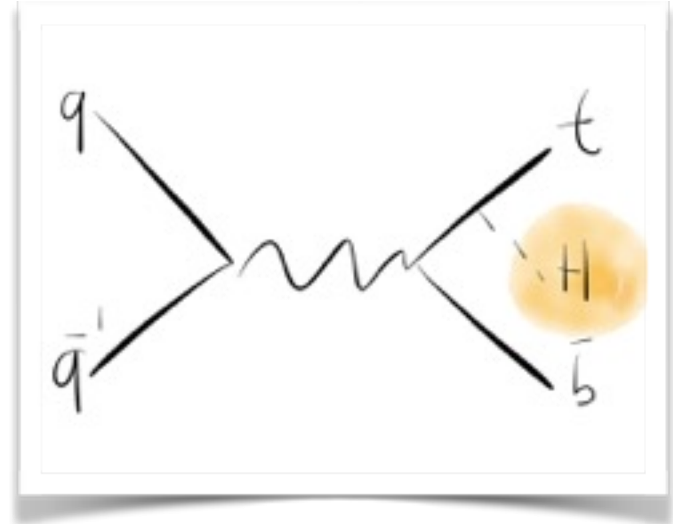


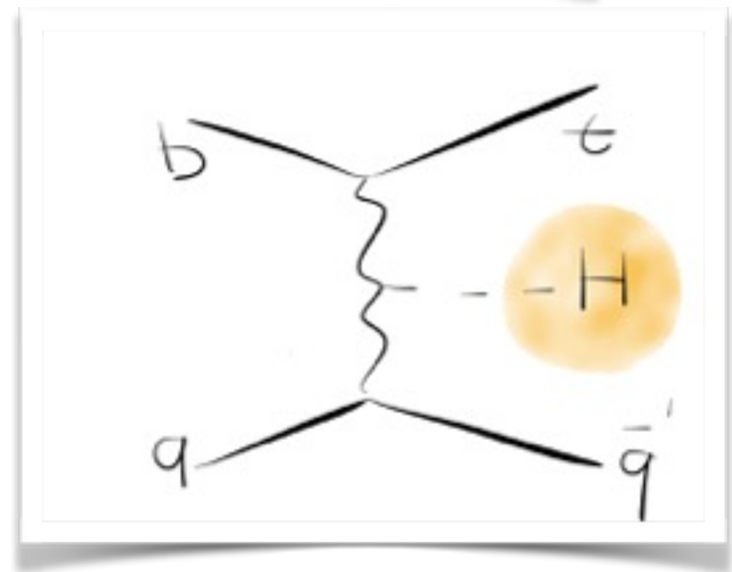


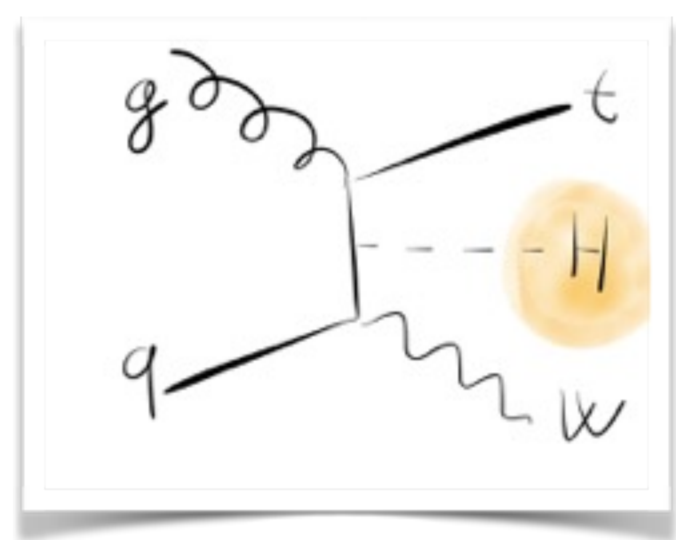
SINGLE TOP PLUS HIGGS











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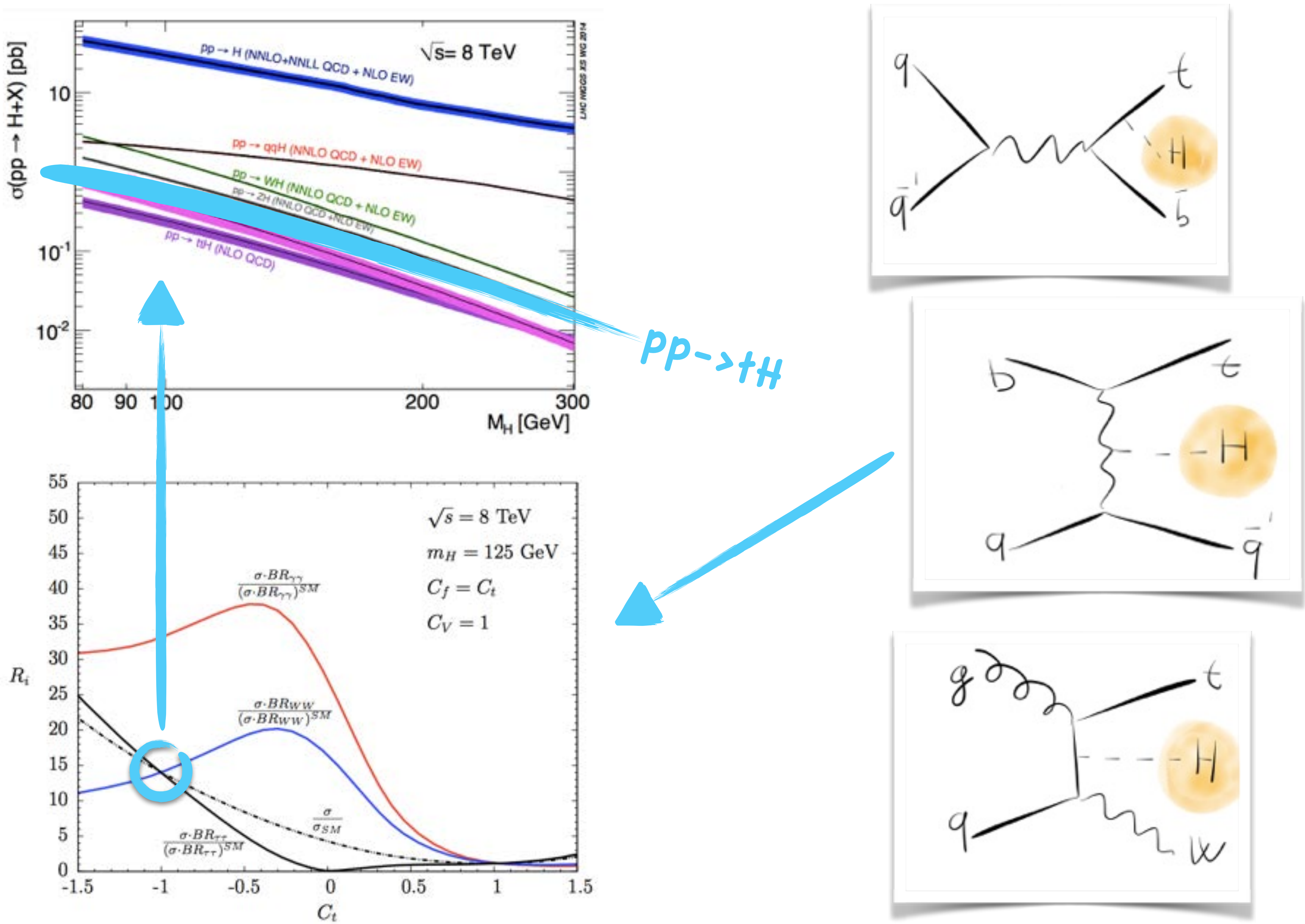
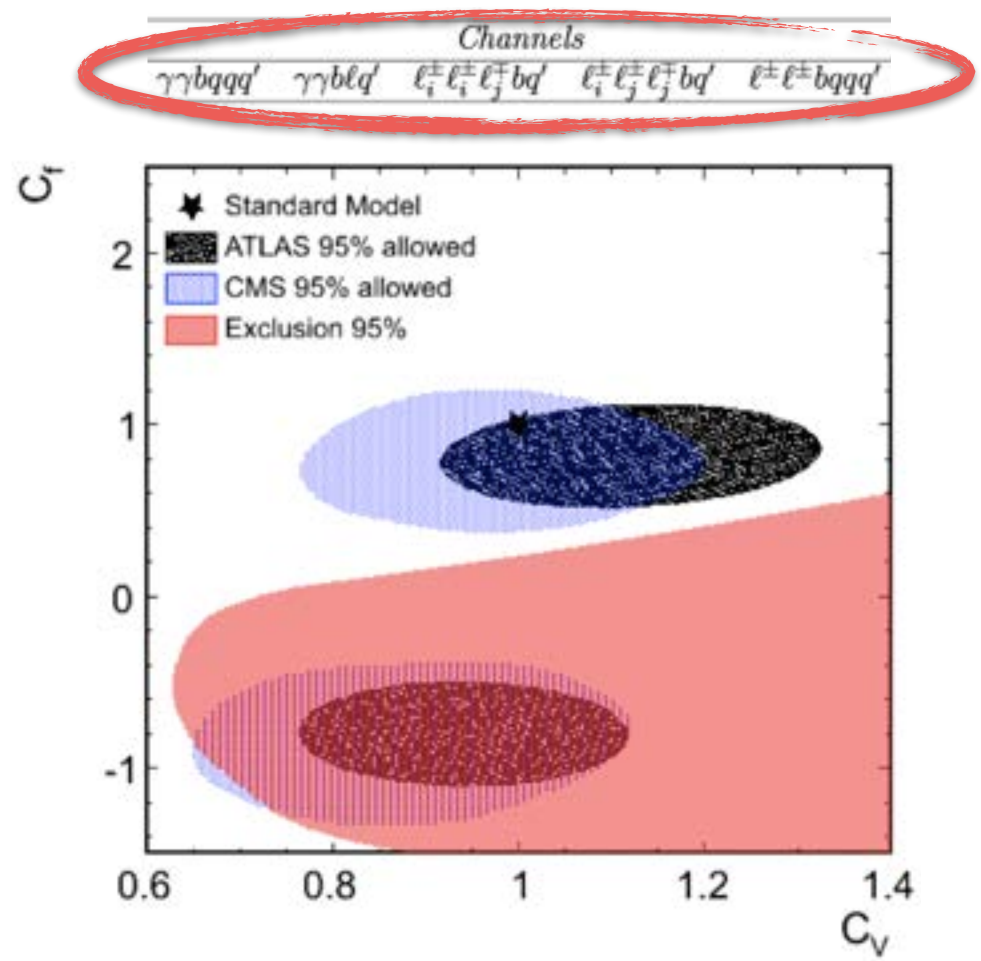
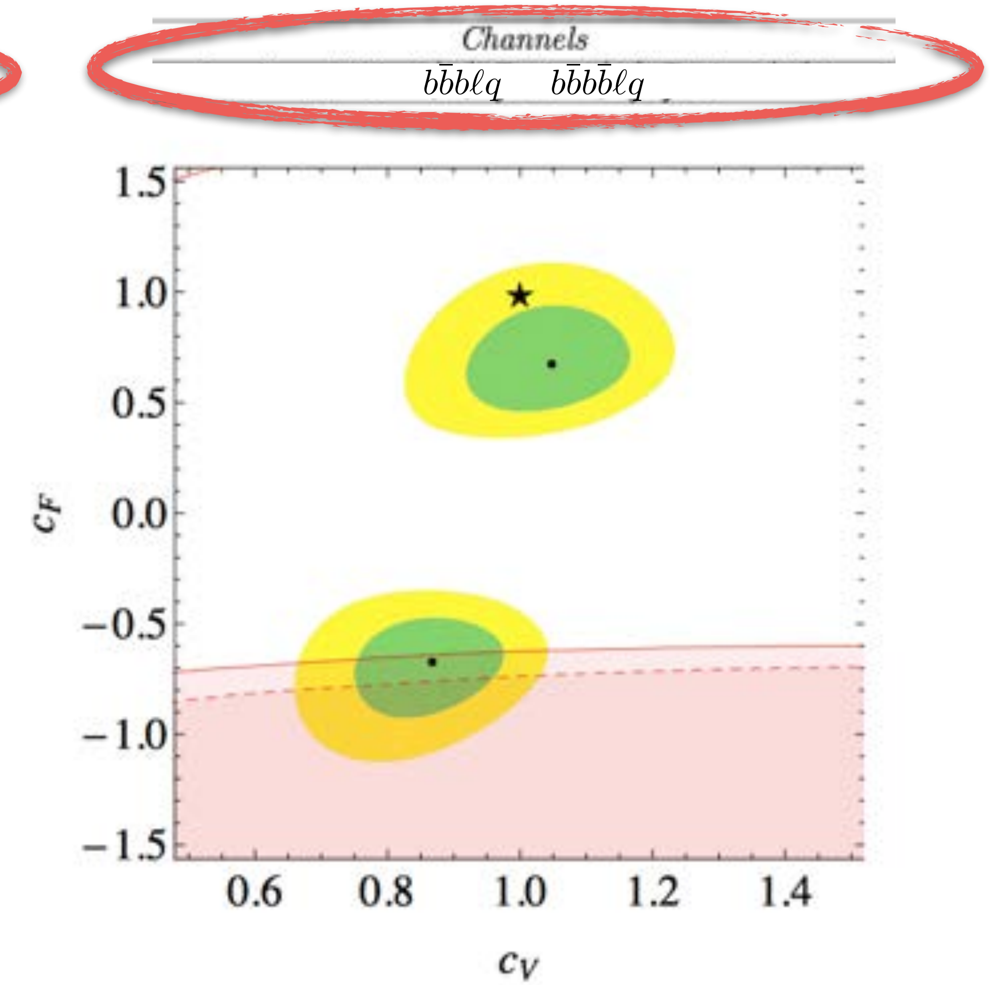


HIGGS COUPLING AND MORE



S.Biswas,E.Gabrielli,FM,B.Mele JHEP 07 (2013) 073

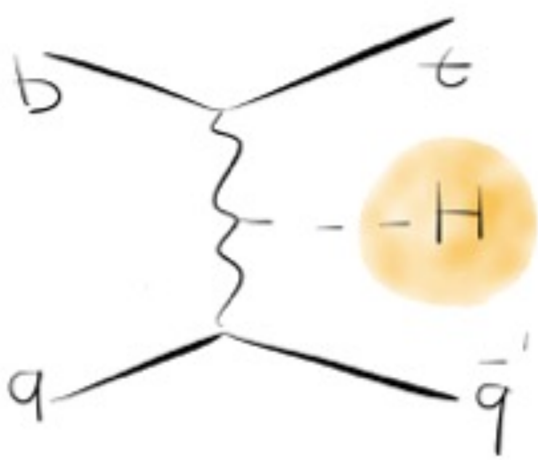


Farina,Grojean,Maltoni,Salvioni,Thamm JHEP 05 (2013) 022

- Several other new physics models could alter single top plus Higgs production rates and/or kinematics:
  - FCNC
  - Composite Higgs
  - CP violation
  - who knows?

tHq: *very* complex final state

- Cross section is only ~1/1000 of the inclusive Higgs production cross section
- Large multiplicity of objects in the final state (signature is dominated by the t/tbar decays)
- Best combination of top and Higgs decays to isolate the small signal - apply lessons learned for ttH!



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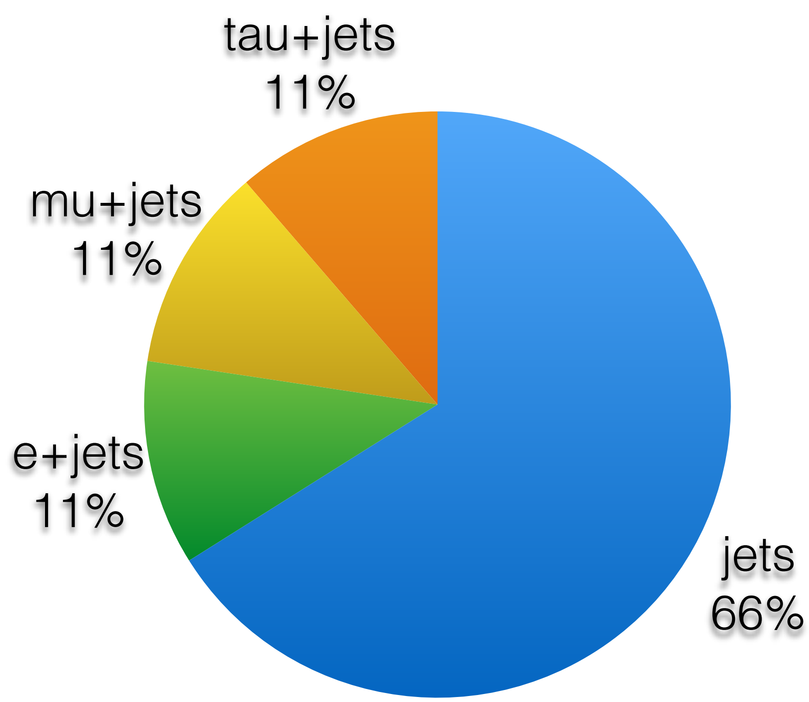

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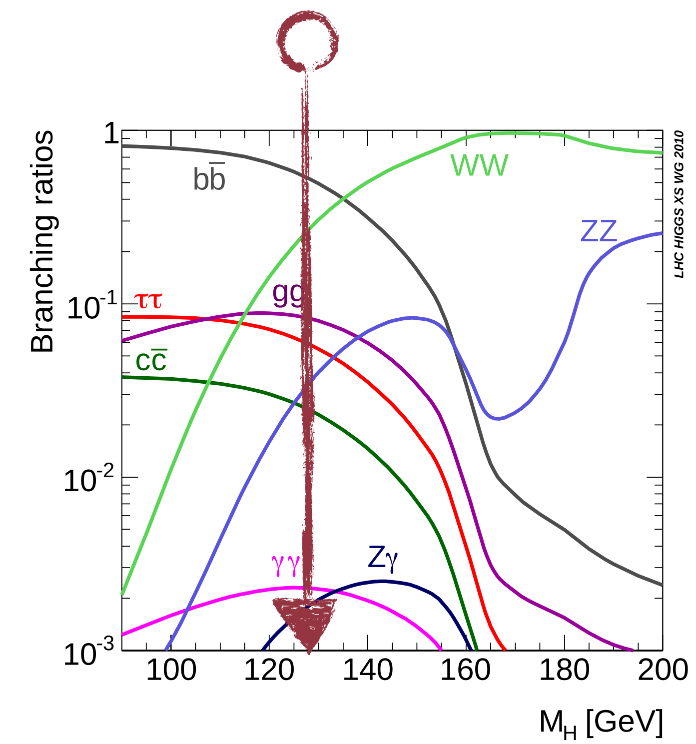

- For the time being, focus on negative Yukawa scenario: cross section O(200fb)
- use only leptonic top quark decay to increase signal-to-background ratio
- now combined result as well! new

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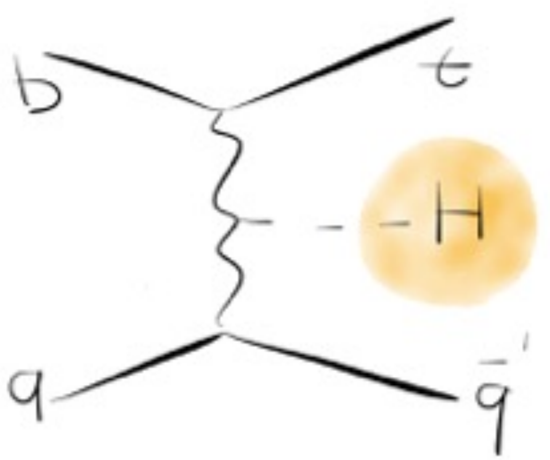
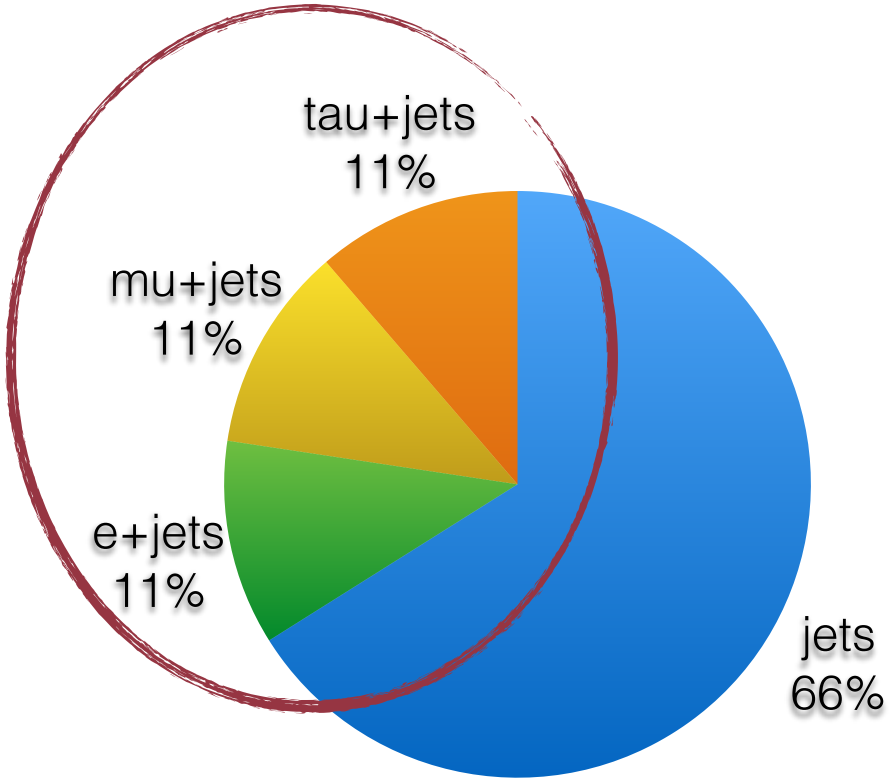


X



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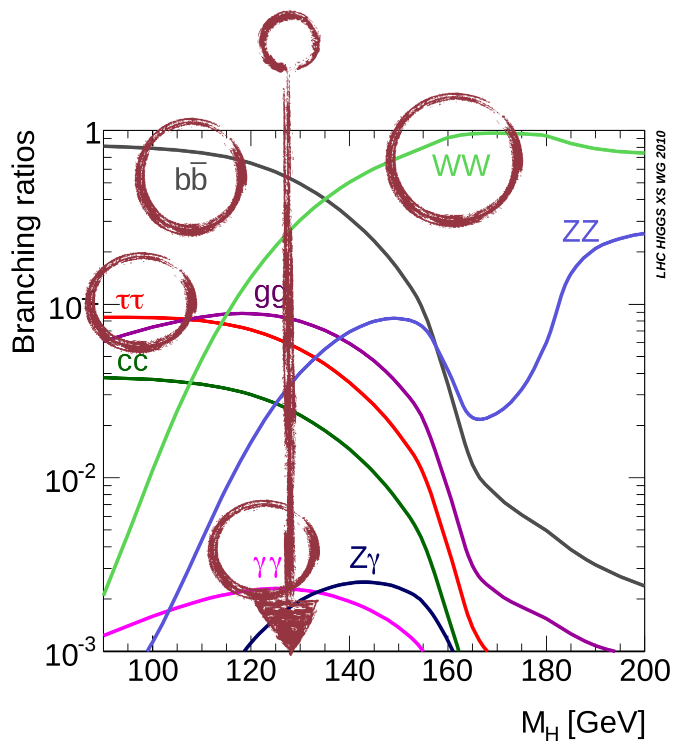

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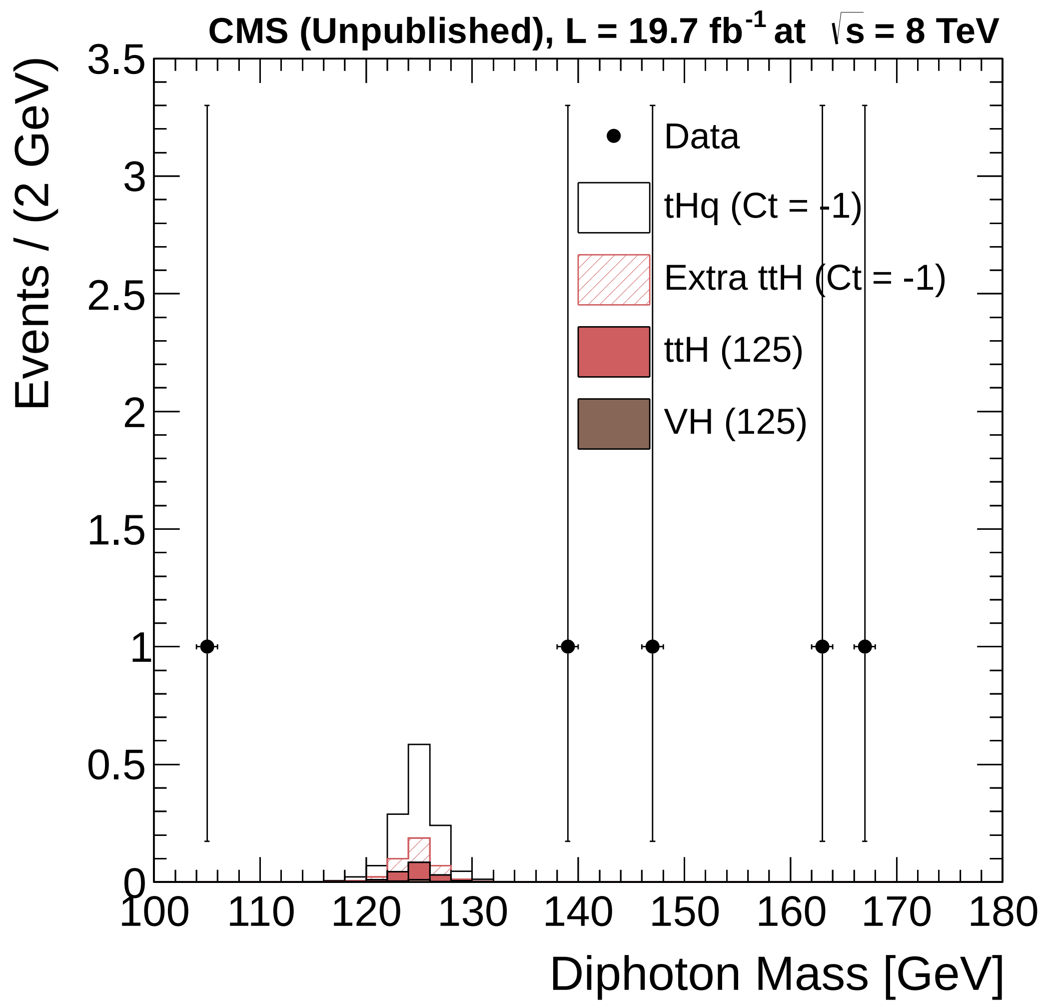
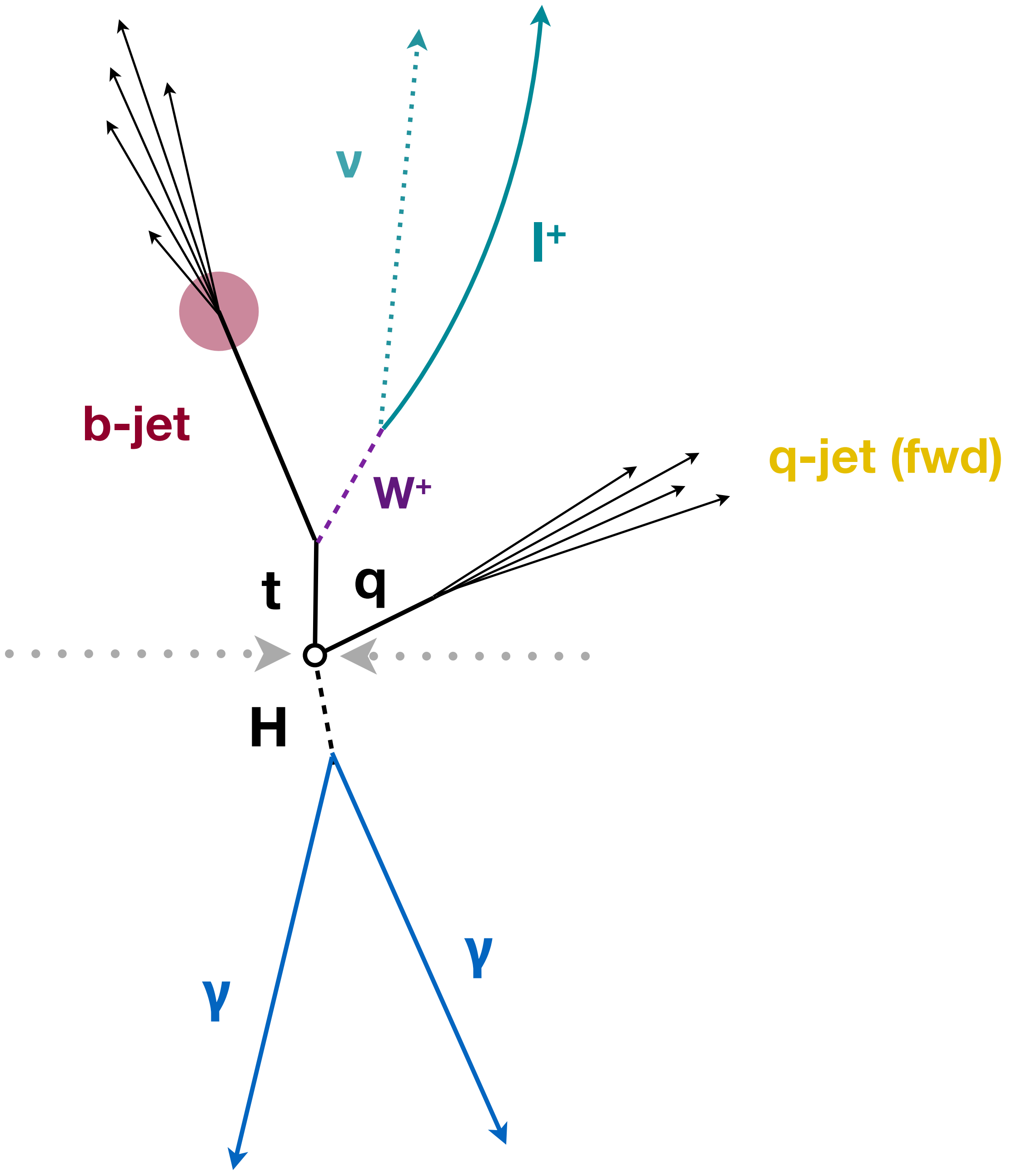
- use only leptonic top quark decay to increase signal-to-background ratio
- now combined result as well!

tHq, Higgs to photons

CMS-HIG-14-001

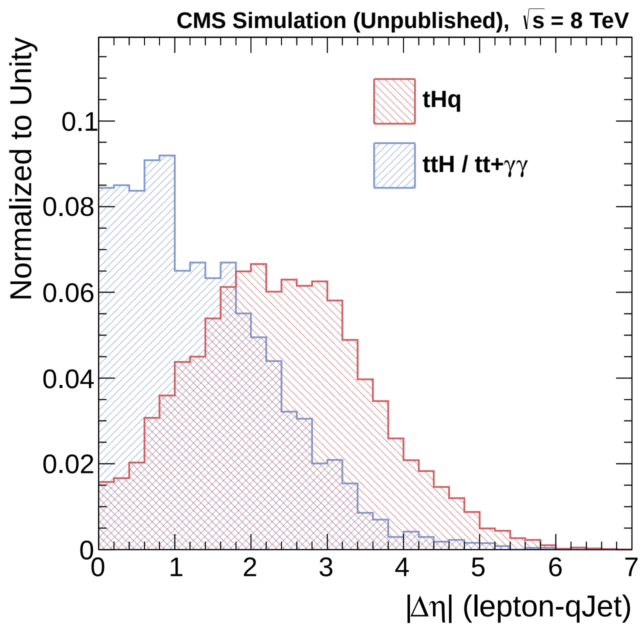
- 2photons with pT >50 ·mγγ/120 and 25GeV
- 1 lepton with > 10 GeV and ΔR > 0.5 w.r.t. photons
- 1 b-tagged jet with > 20 GeV
- No cut on E/T
- Hardest additional jet, must have pT > 20 GeV and |η| > 1

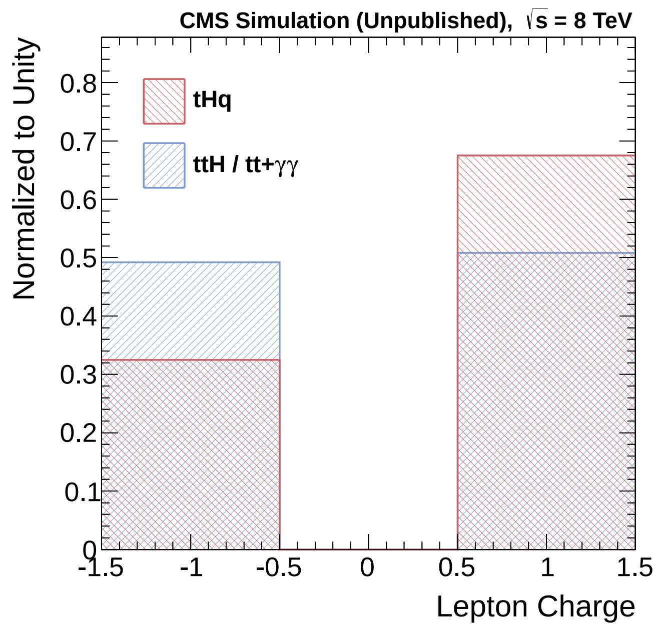


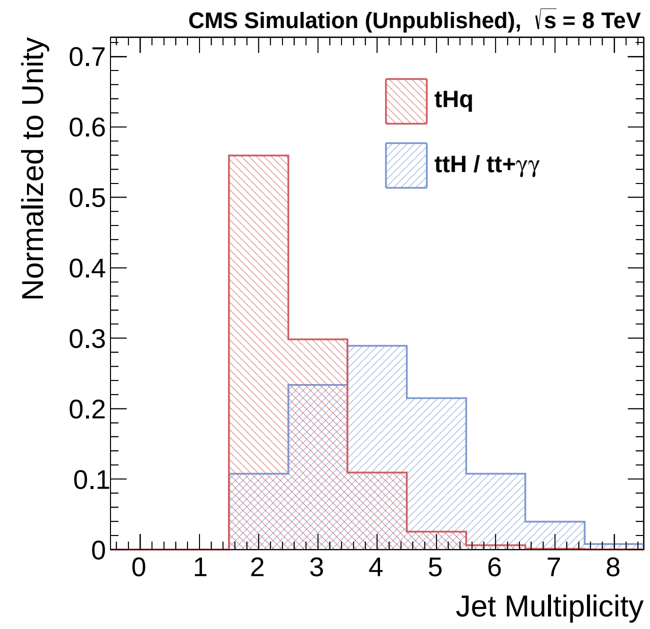


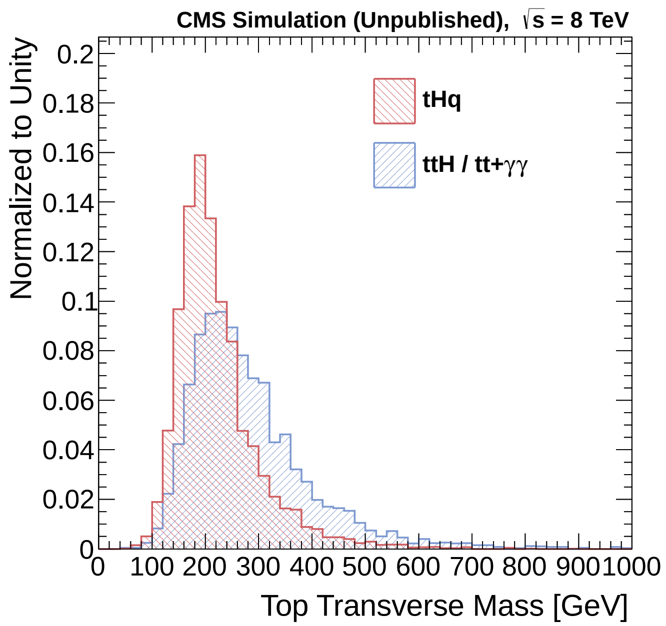
tHq, Higgs to photons

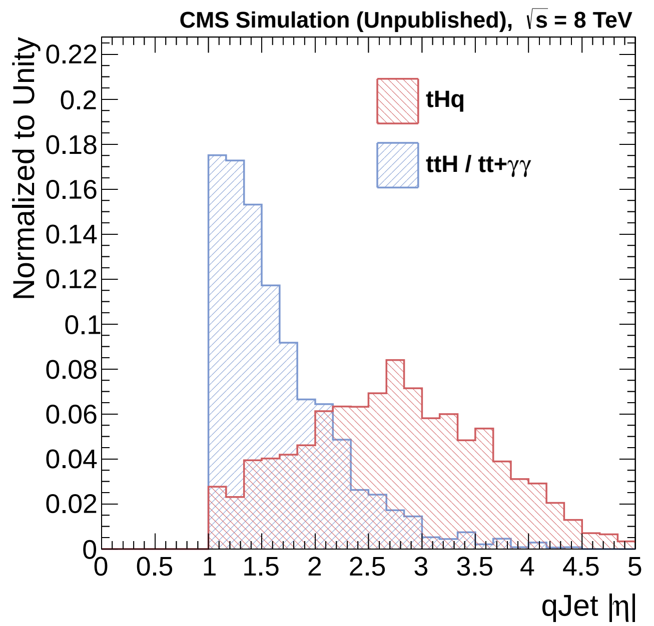
CMS-HIG-14-001

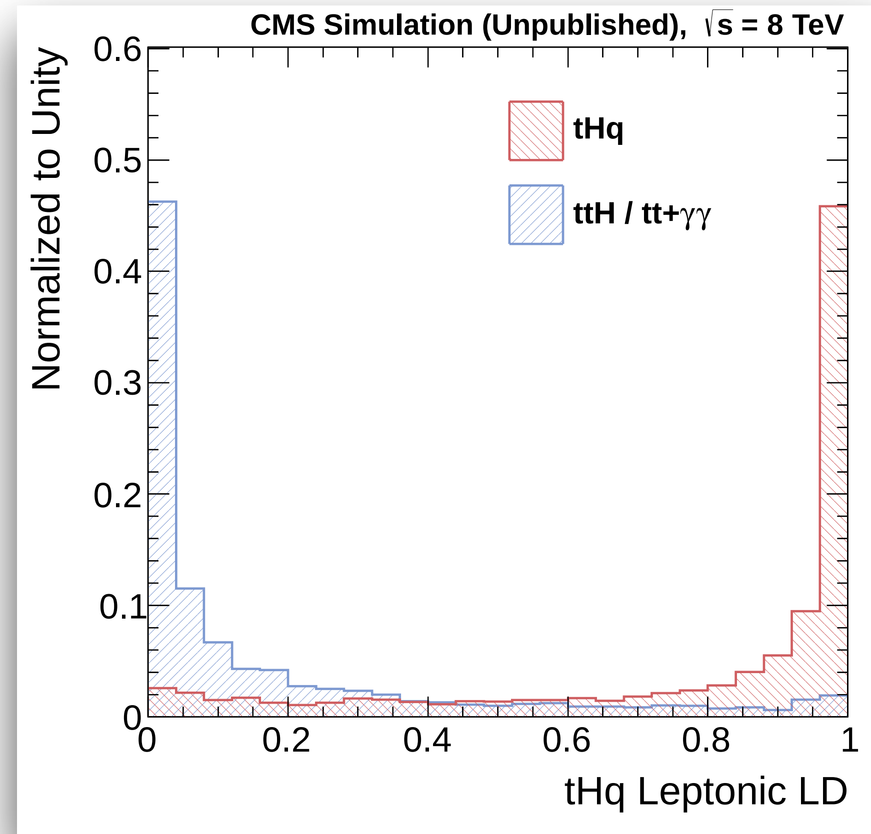






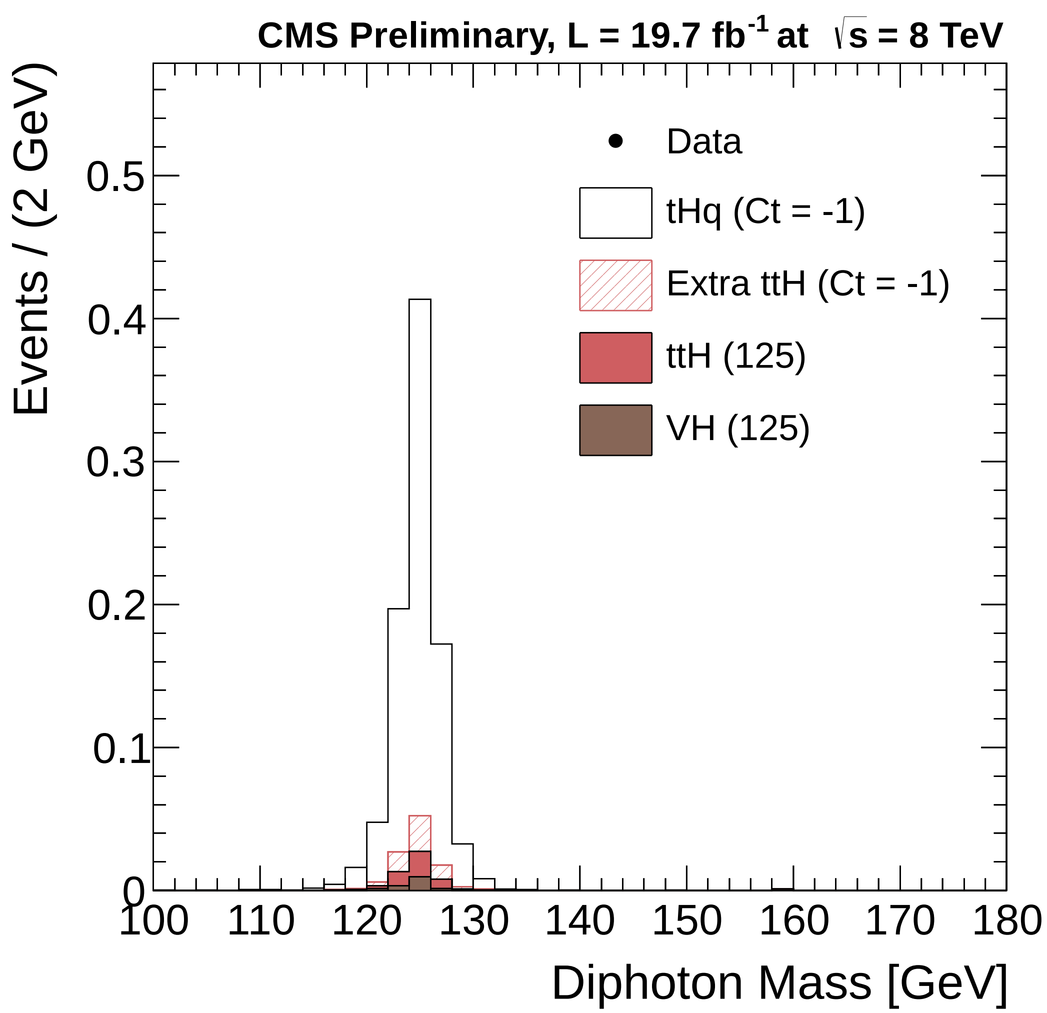






tHq, Higgs to photons

CMS-HIG-14-001

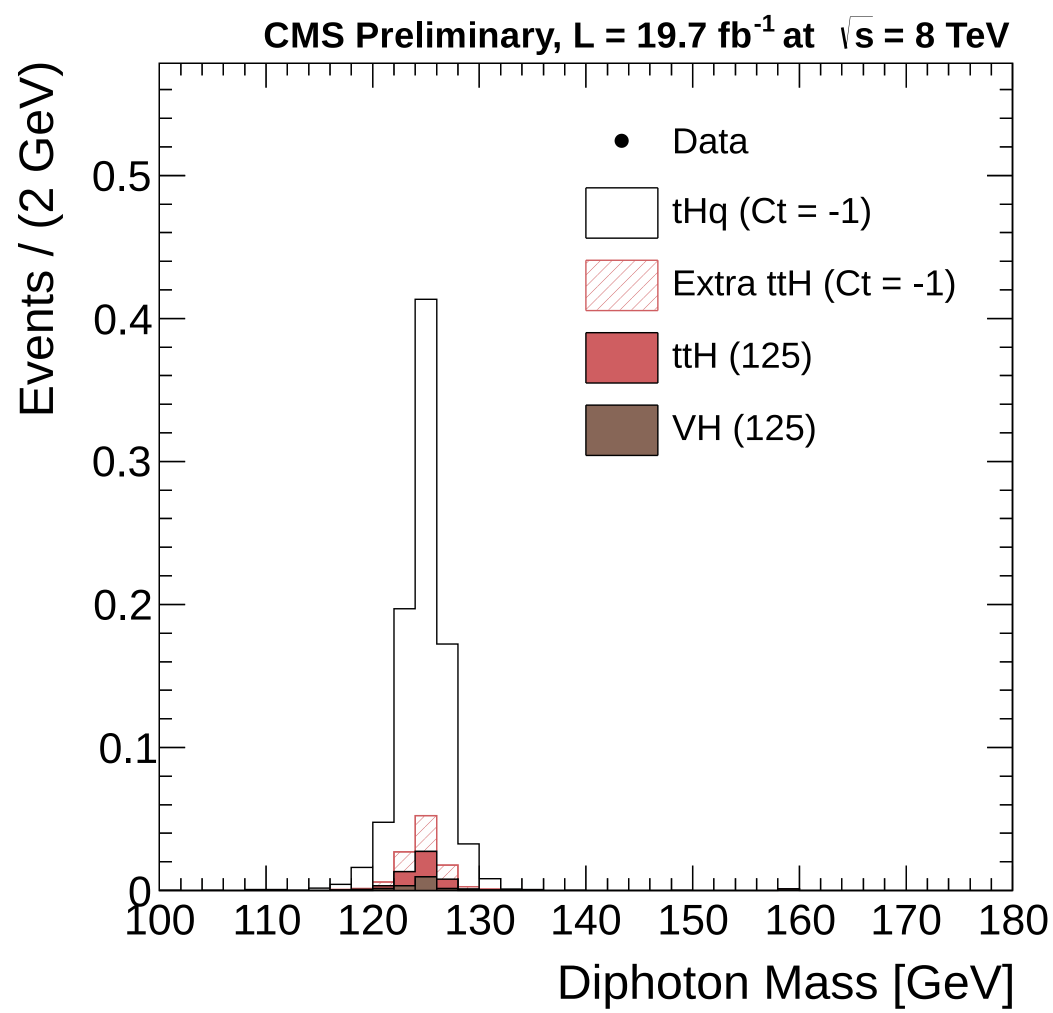


Process	Yield
tHq ($C_t = -1$)	0.67
$t\bar{t}$H	$0.03 + 0.05^{\dagger}$
VH	$0.01 + 0.01^{\dagger}$
other H	0

- No events in the signal region
- Non-resonant background estimation via fit in loosened m(γγ)-sideband regions
- Set 95% upper level confidence limit of 4.1 the sigmaXBR for tHq production with negative Yukawa

tHq, Higgs to photons

CMS-HIG-14-001



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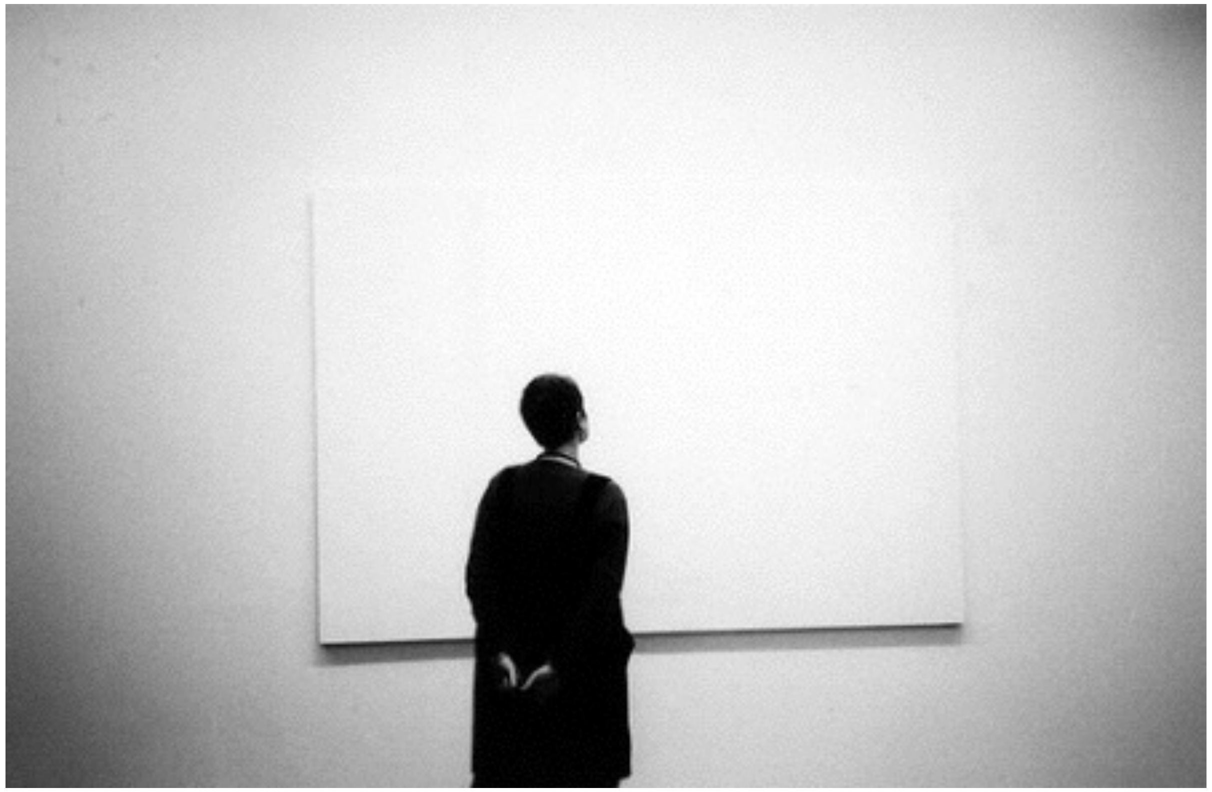
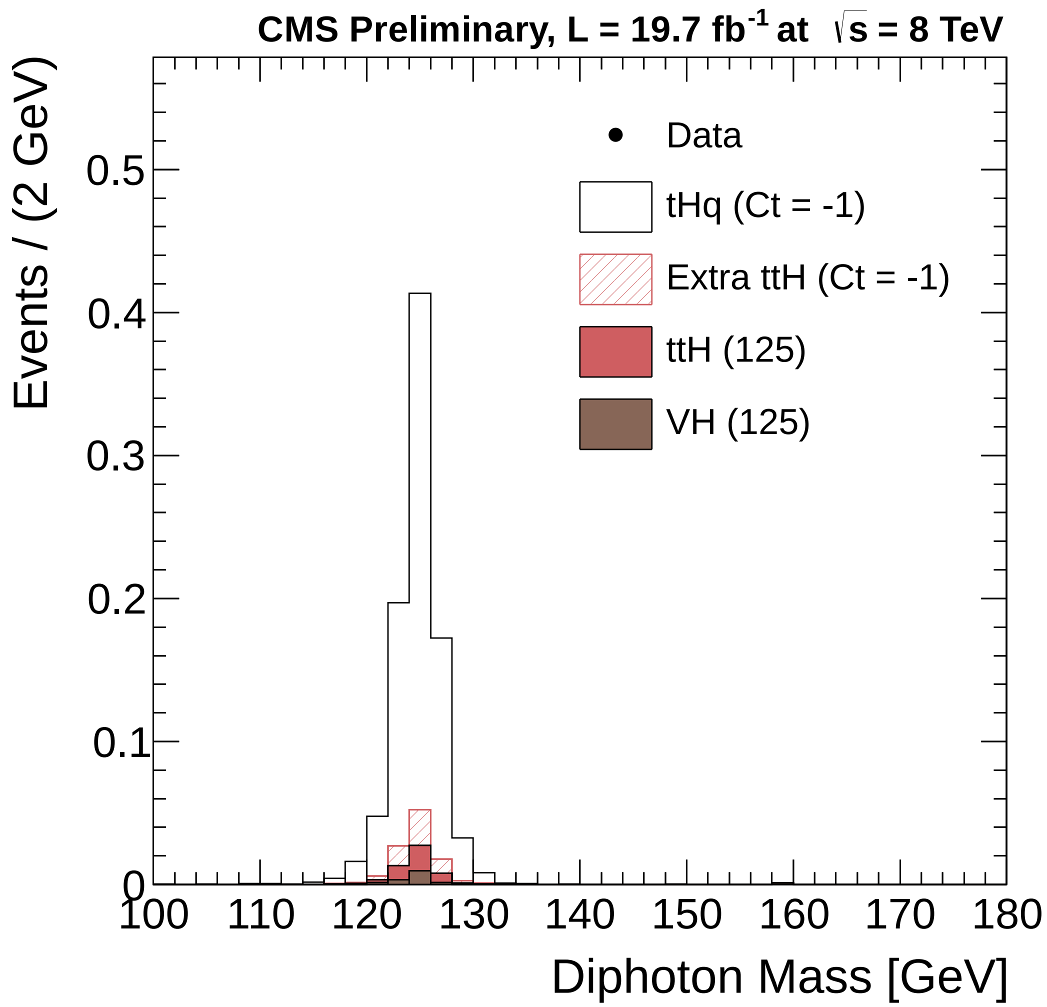


tHq, Higgs to photons

CMS-HIG-14-001



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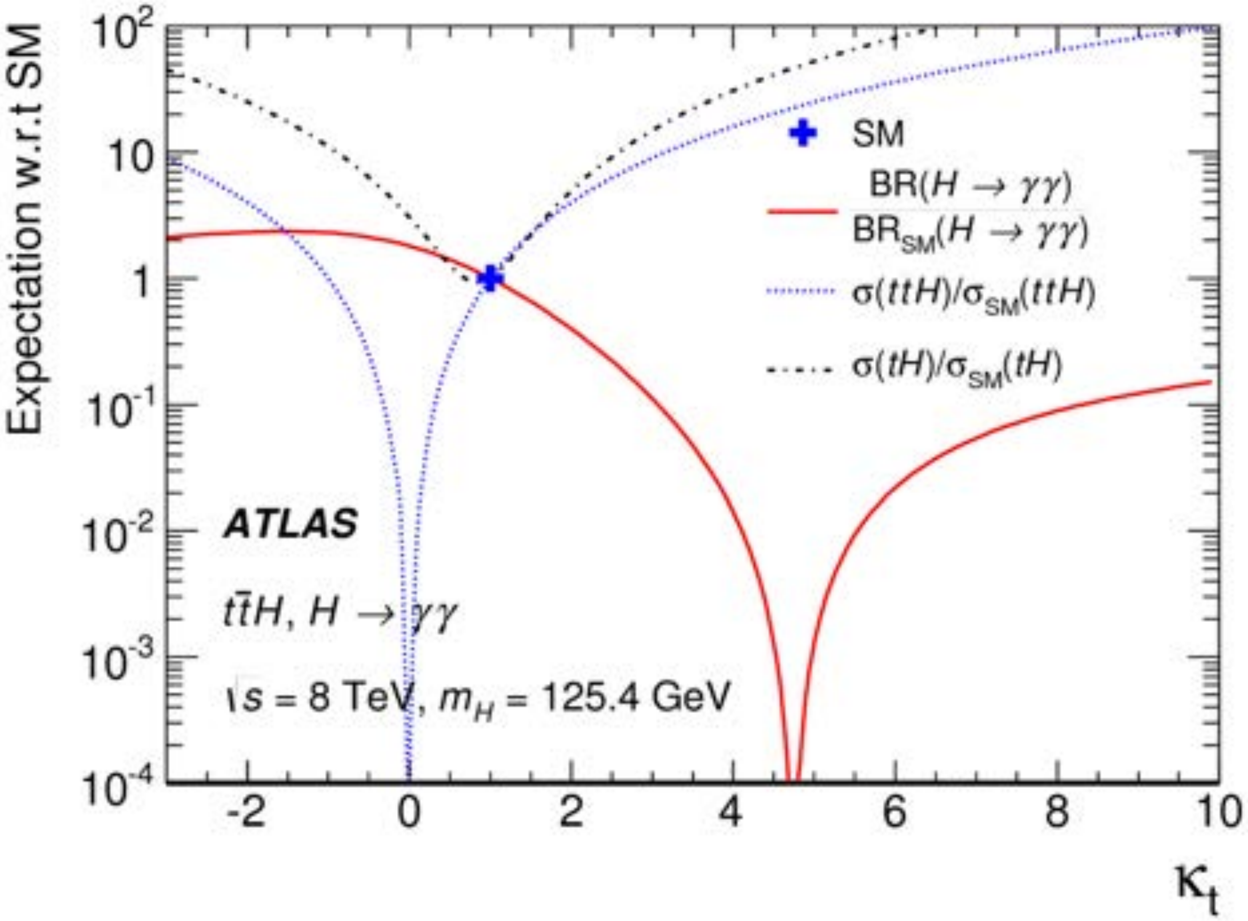
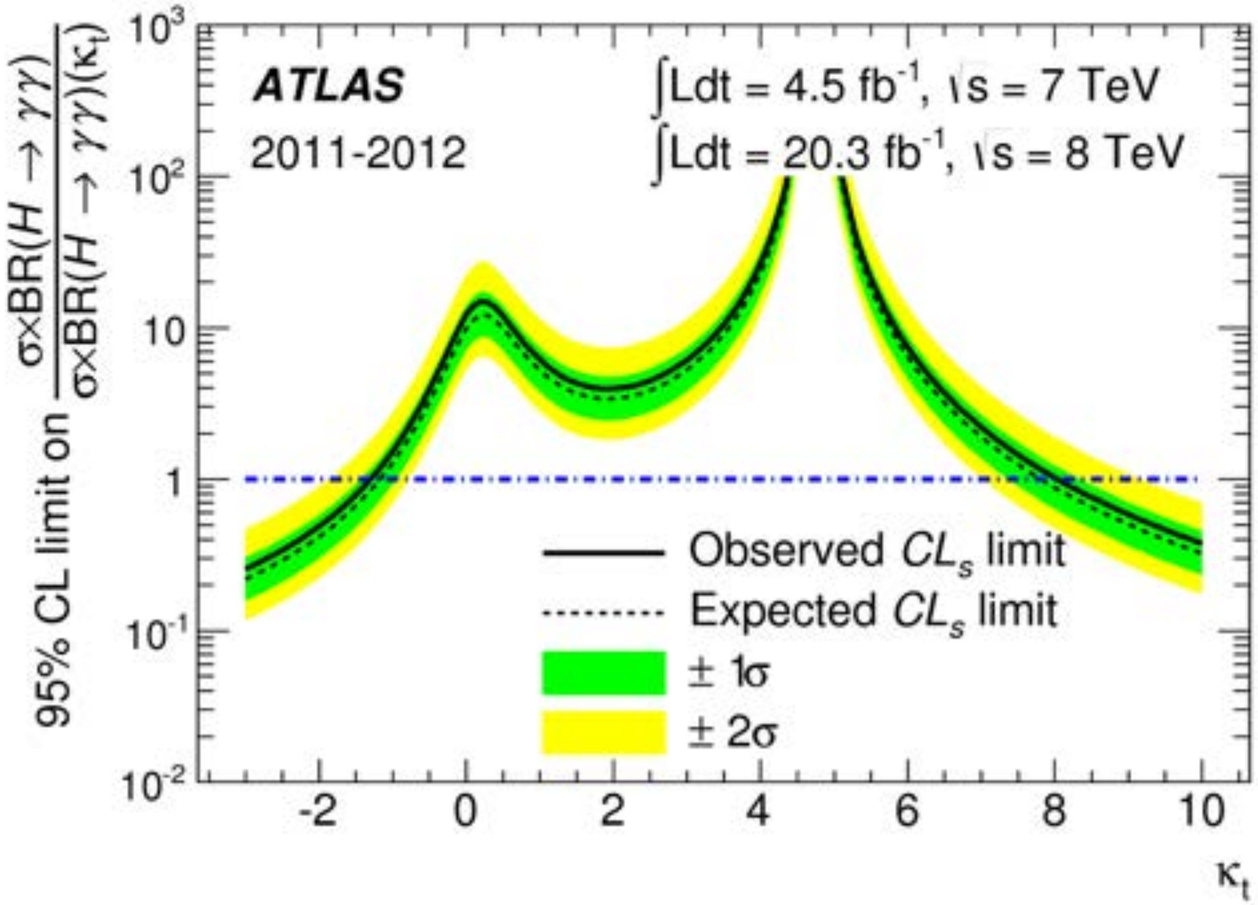
THE ATLAS WAY TO YUKAWA

- ATLAS uses a different approach to negative Yukawa:
- take existing ttH analysis, consider all tH contributions to it, study the dependence of the sum of tH+X processes as a function of Ct

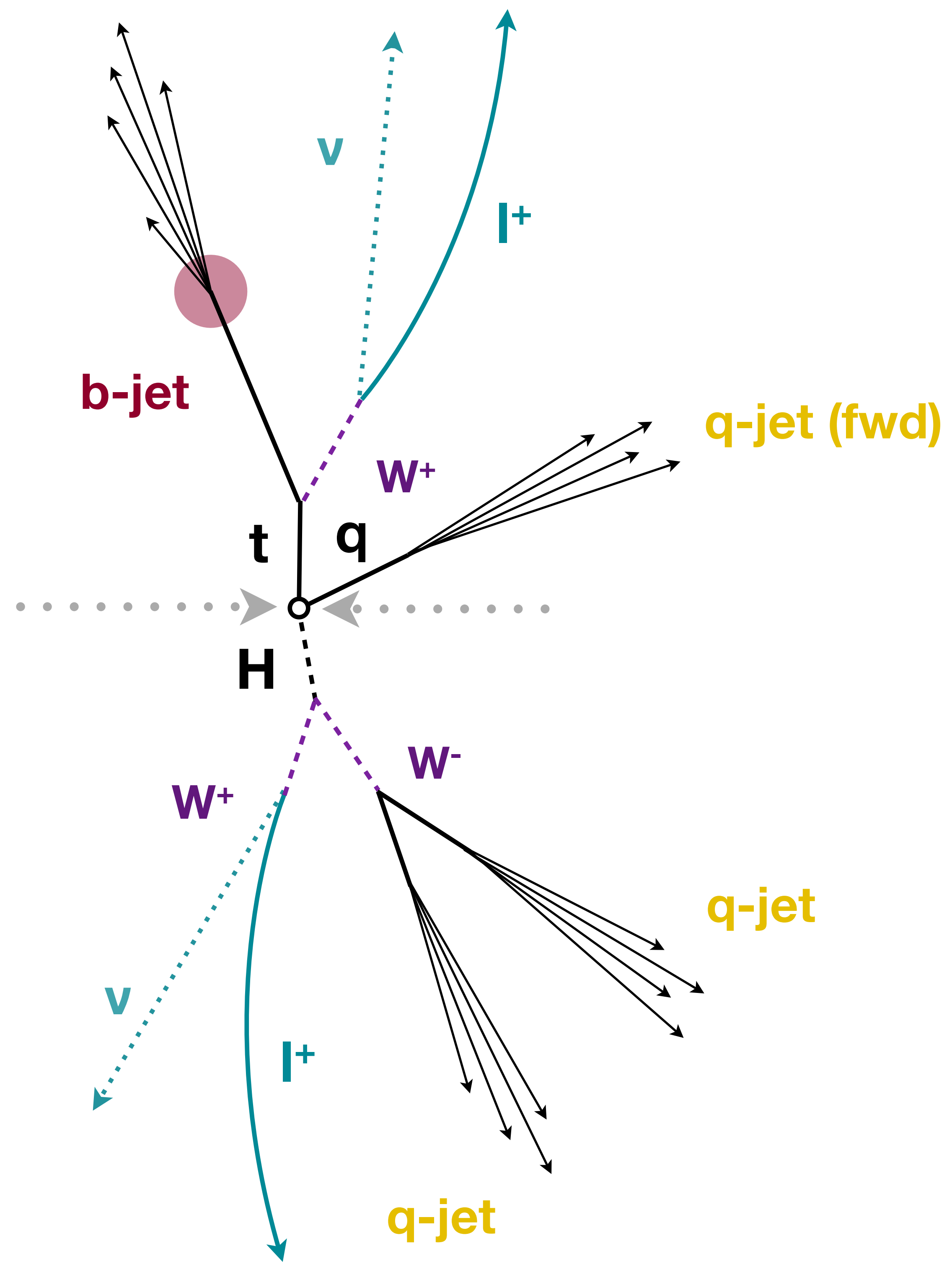




tHq to multilepton

- Three W bosons
- One b-jet
- One light (forward) jet

- Best channels for H->WW):
  - same sign dileptons



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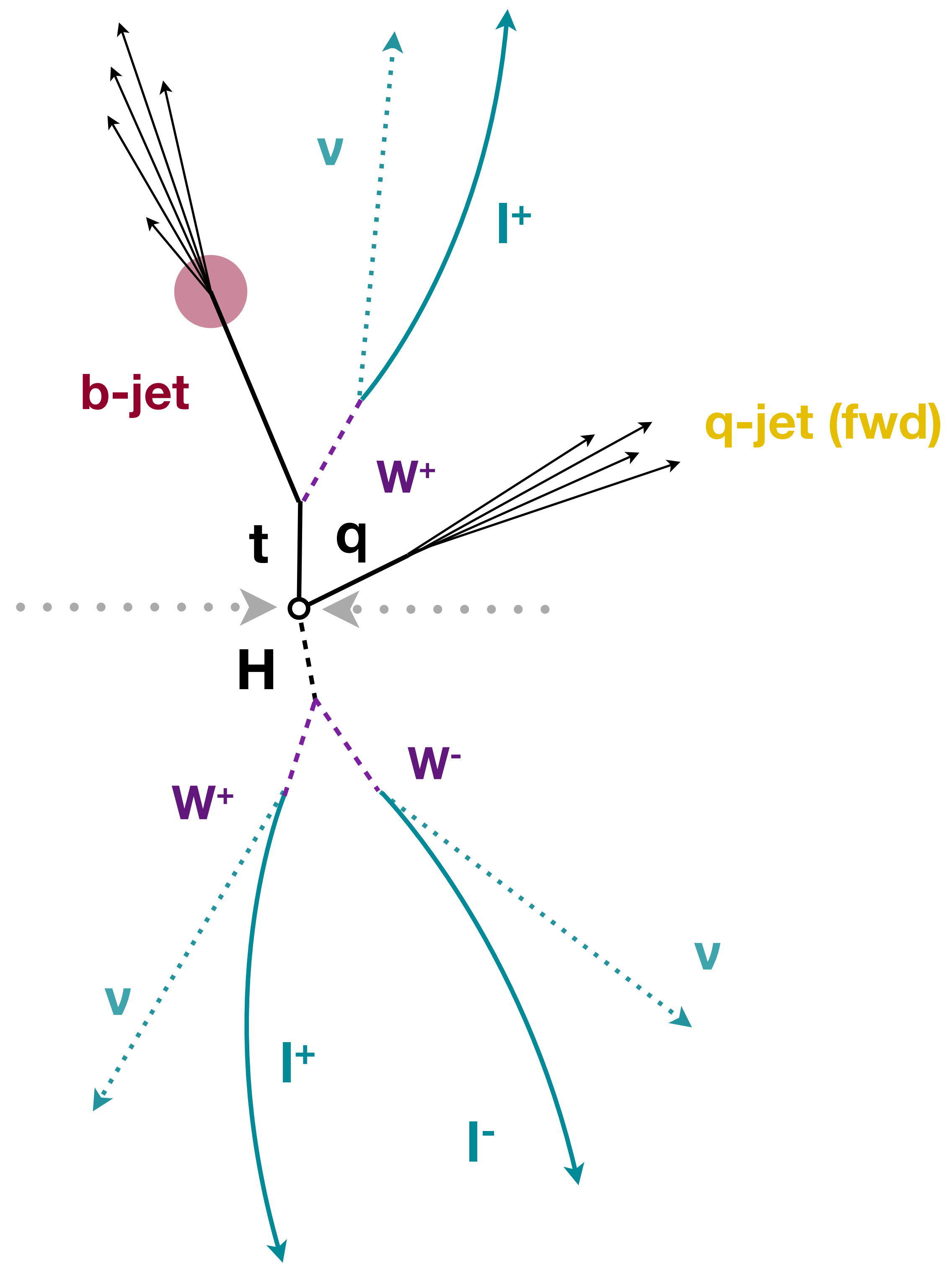


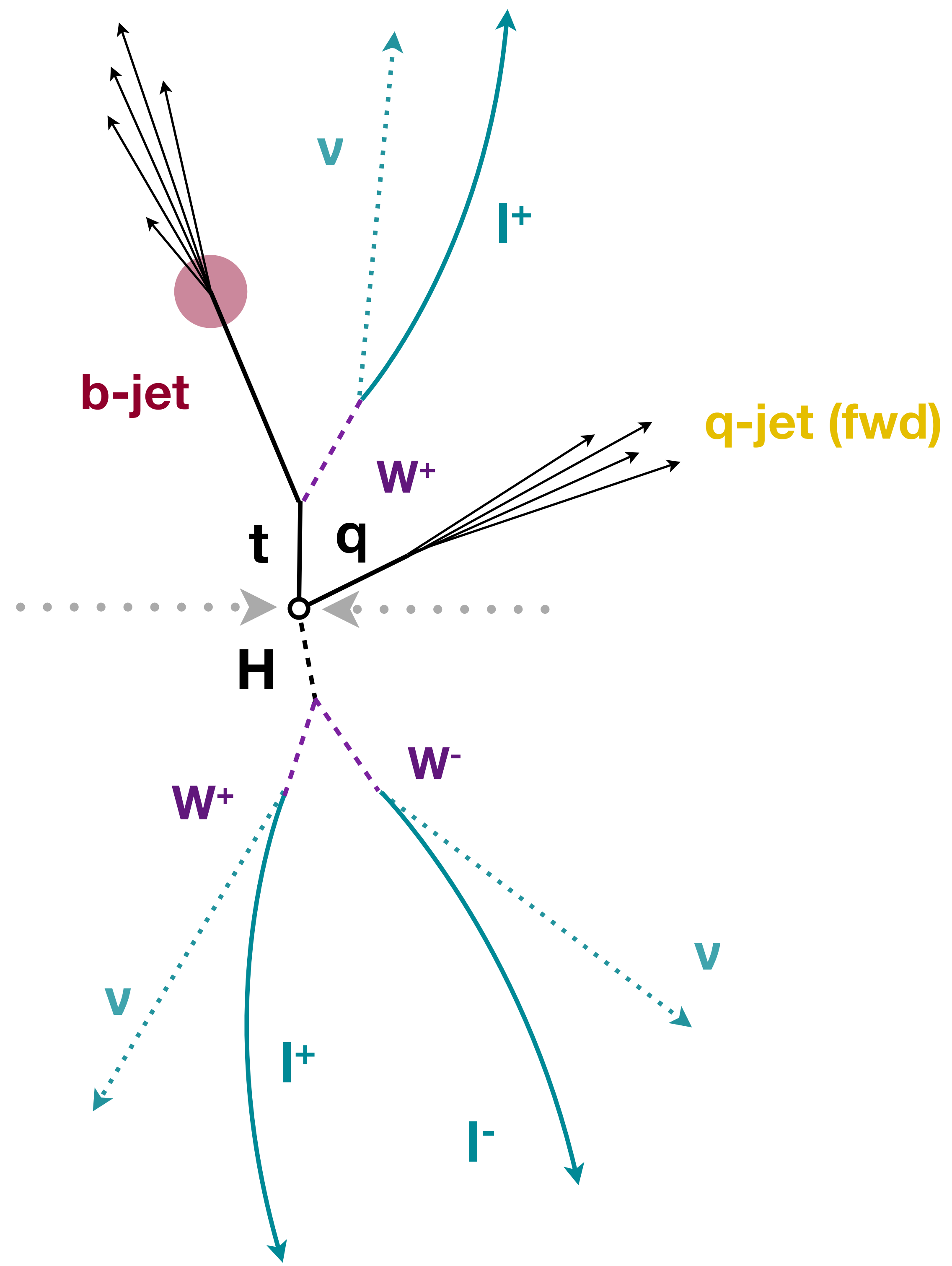
tHq TO MULTILEPTON

- Three W bosons
- One b-jet
- One light (forward) jet

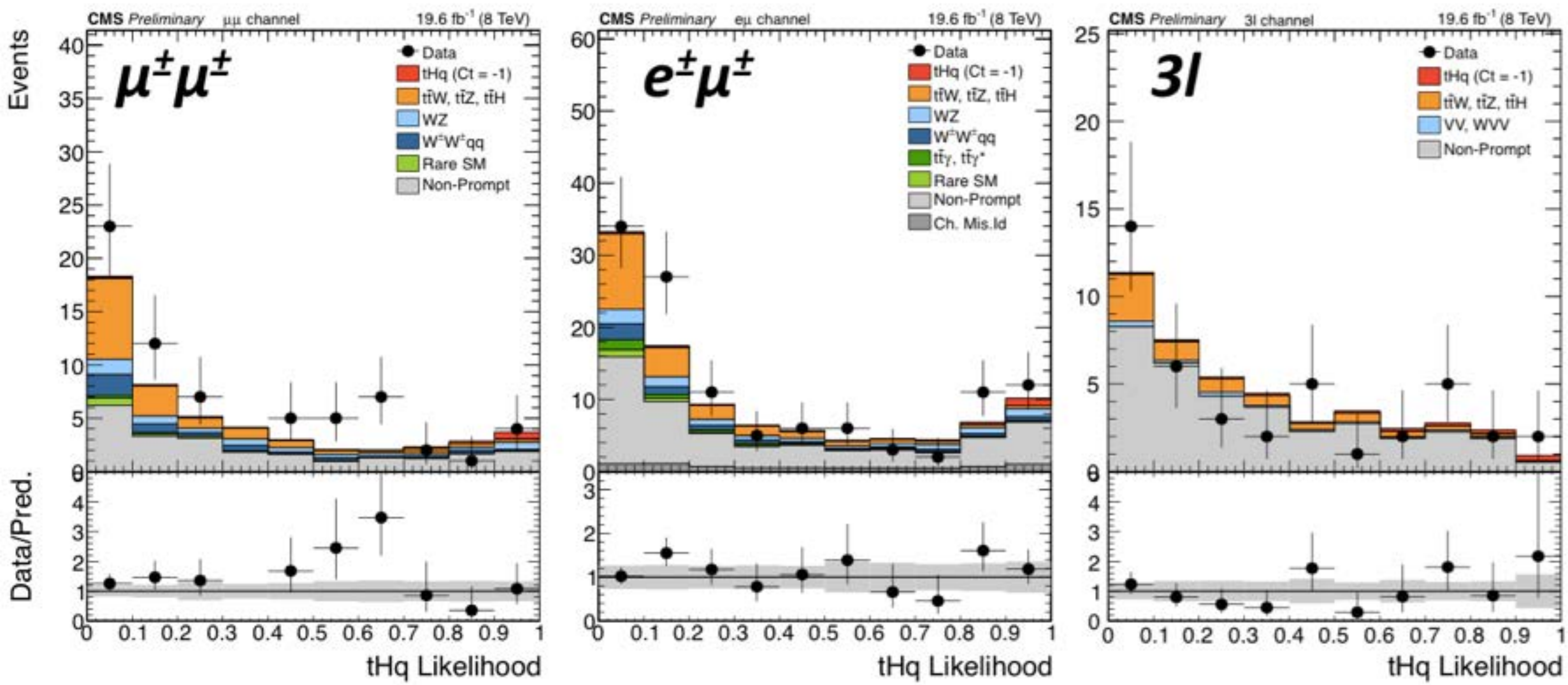
- Best channels for H->WW):
  - same sign dileptons
  - three leptons

- Leptons:
  - pt>20GeV(SS2L) 10GeV (3L)
  - ttH derived machine-learning-optimized lepton identification (SS2L)

- Jets
  - pt>25GeV eta < 4.7
  - CSV b-tagging



tHQ TO MULTILEPTON

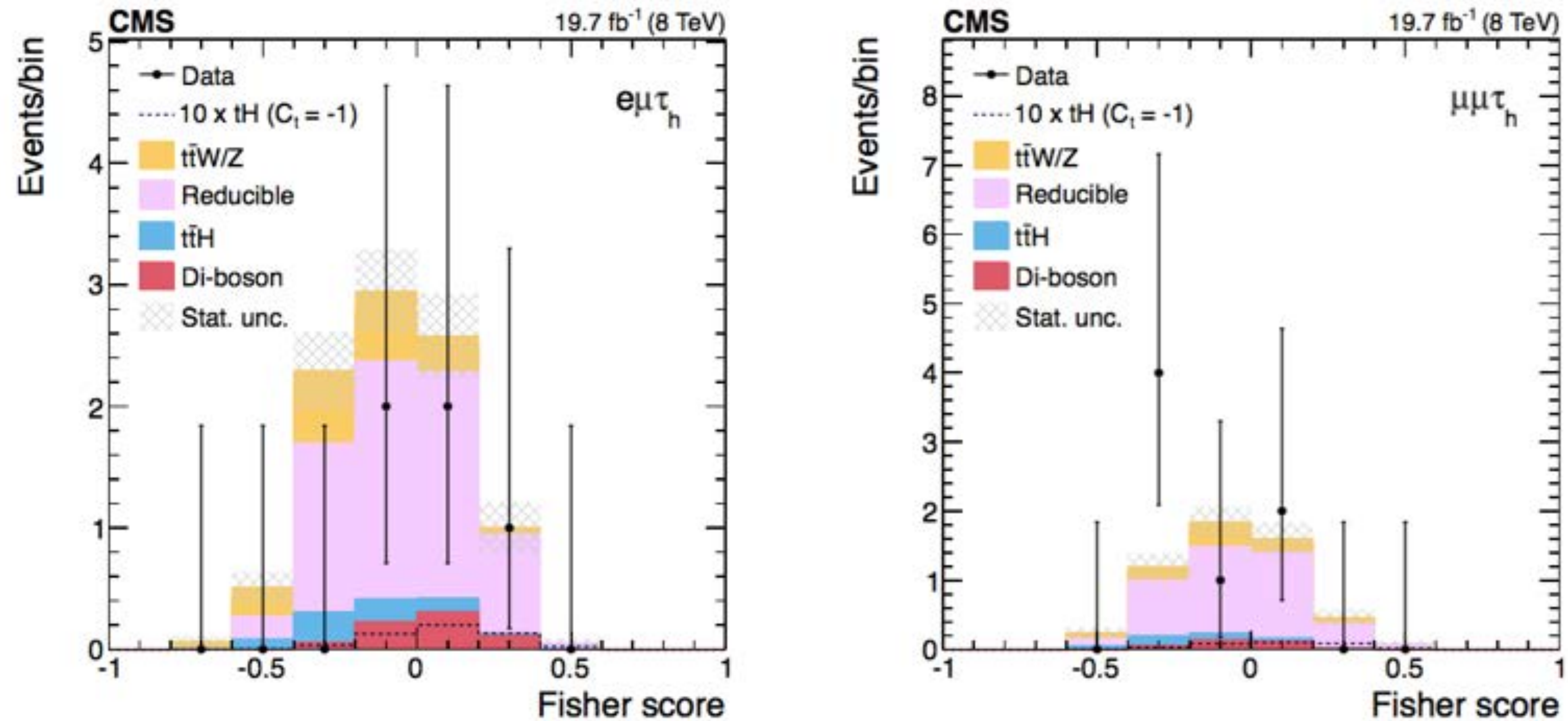


No significant signal - setting 95% confidence level upper limits

Channel	Observed	Expected	68% prob. band	95% prob. band
SS $\mu\mu$	9.3	8.1	[6.0, 11.8]	[4.7, 16.7]
SS $e\mu$	11.4	9.3	[7.0, 13.5]	[5.4, 18.8]
3ℓ	11.5	8.6	[6.6, 12.4]	[5.7, 18.0]
combined	6.7	5.0	[3.6, 7.1]	[2.9, 10.3]

expected (observed) limit at 5 (6.7) times cross section on sigma(tHq, Ct=-1)

tHq to multilepton + tau



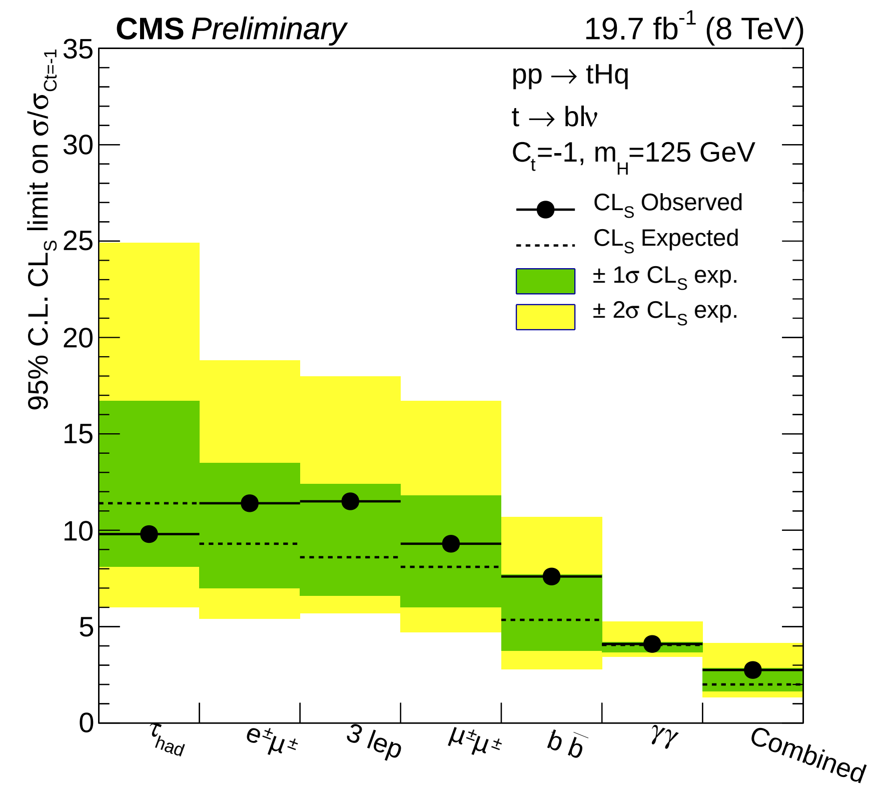
Process	$e\mu\tau_h$	$\mu\mu\tau_h$
tHq, $C_t = -1$	0.42 ± 0.05	0.26 ± 0.03
tHW, $C_t = -1$	0.06 ± 0.01	0.04 ± 0.01
$t\bar{t}H$	0.6 ± 0.1	0.3 ± 0.1
$t\bar{t}V$	1.8 ± 0.4	0.9 ± 0.2
VV	0.7 ± 0.1	0.3 ± 0.1
Reducible	6.3 ± 3.1	4.5 ± 1.9
Tot. background	9.5 ± 3.7	5.4 ± 2.4
Data	5	7

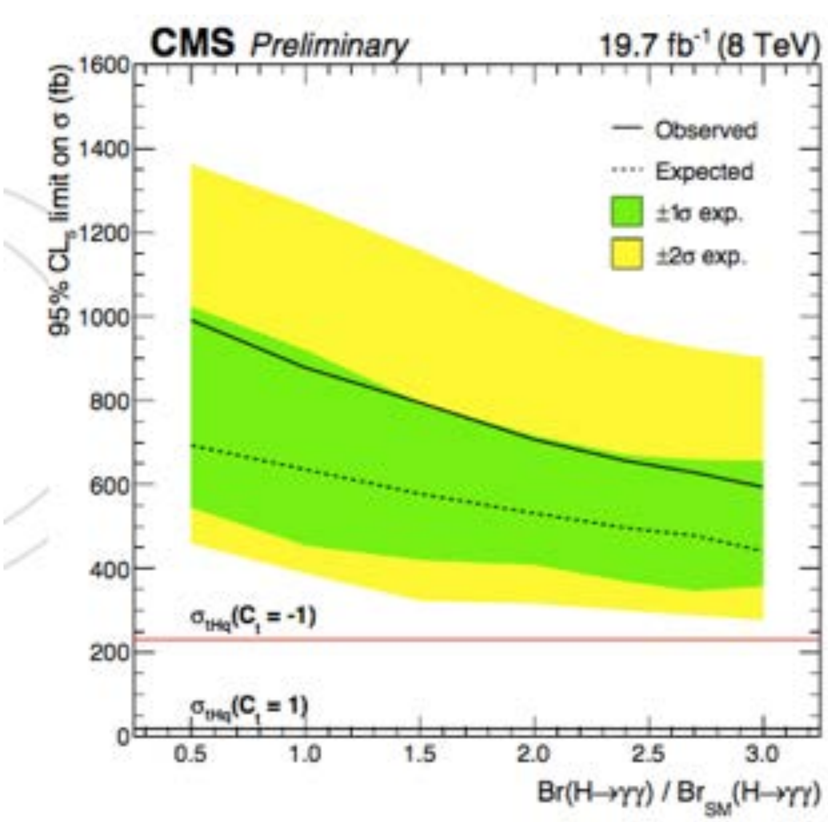
COMBINATION AND INTERPETATIONS

Interpretation #1

Limits on the event yields on the analyzed channels, predicted by the inverted Yukawa sign hypothesis:

2.1 (2.8) exp (obs) on Yt=-1 event yields prediction

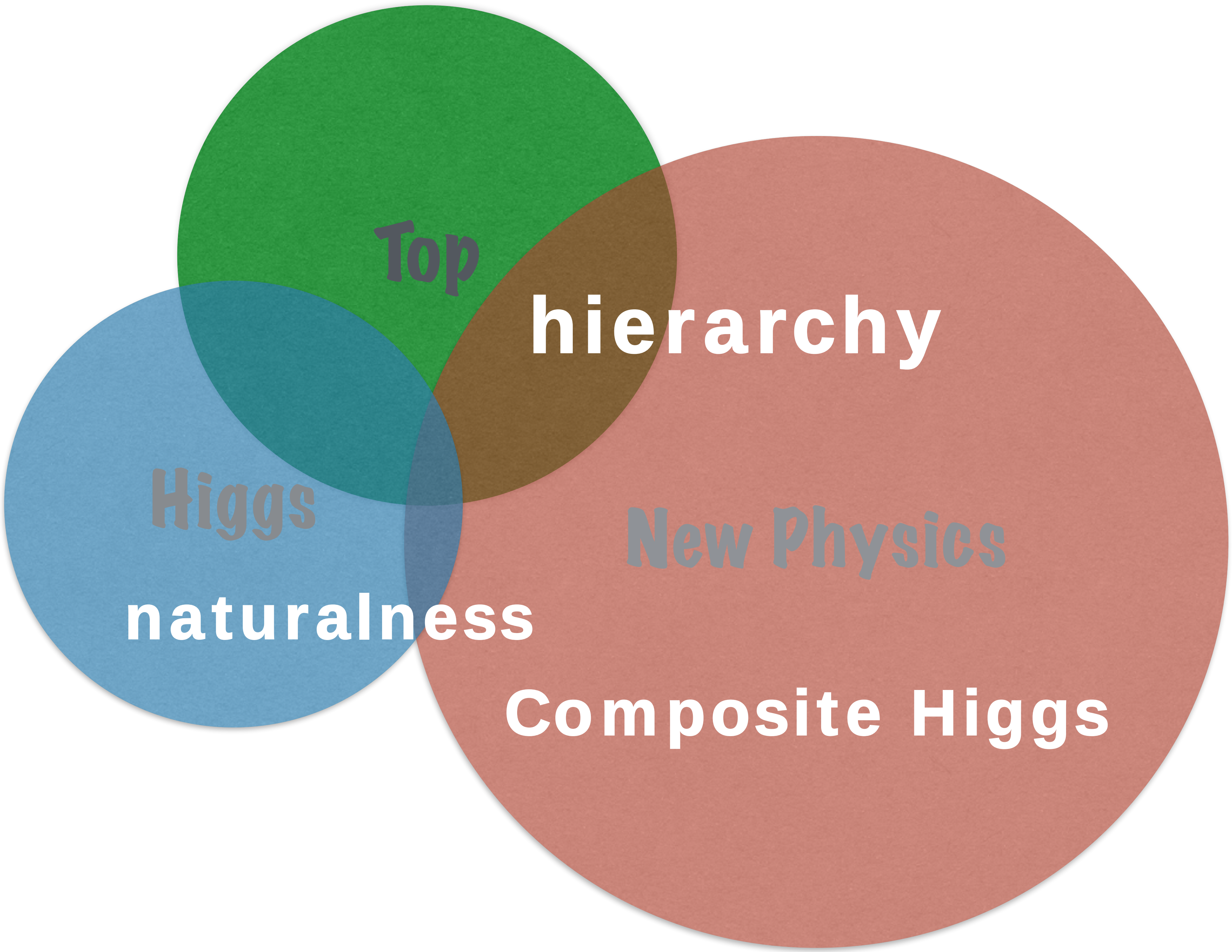




Interpretation #2

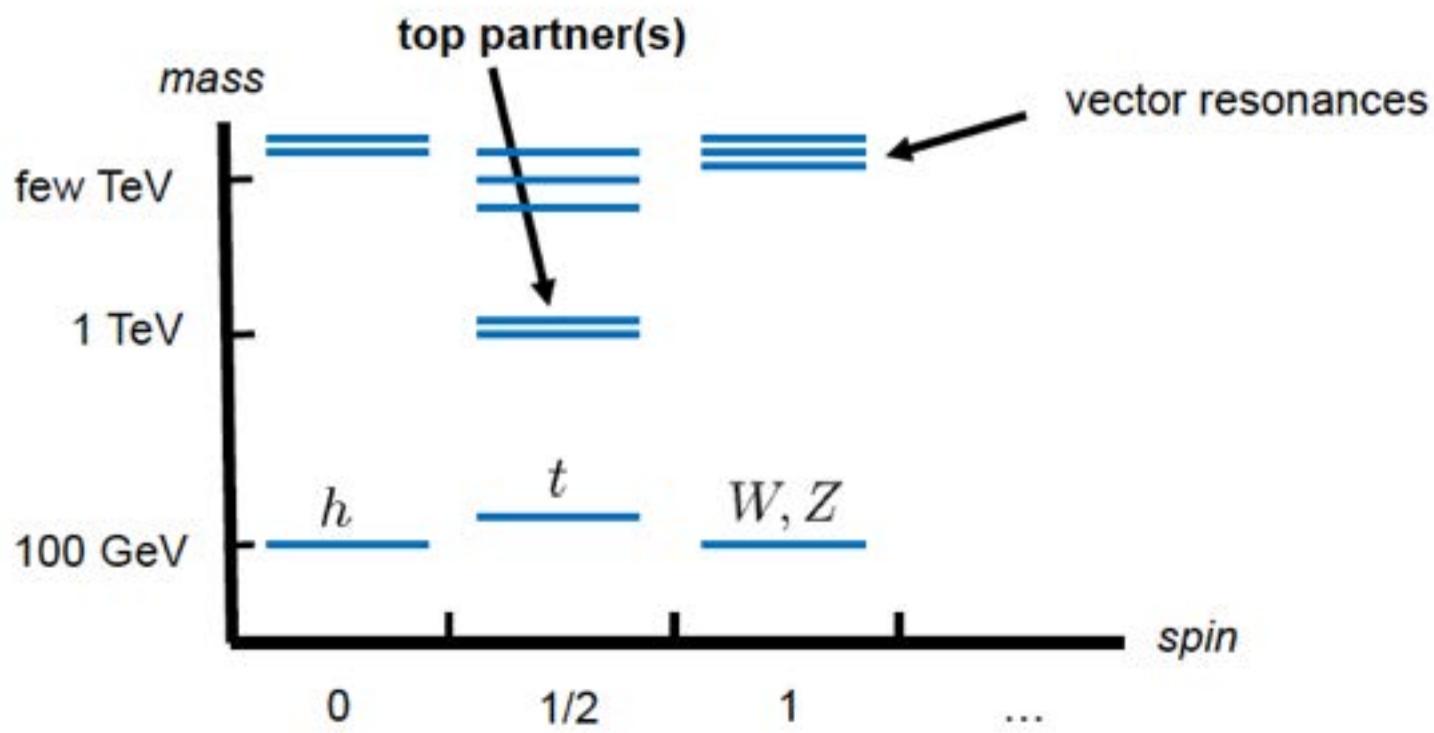
generic limits on single top plus Higgs production scanning values around SM Higgs to diphoton decay:

Upper limit of 700(1000) - 425(600)fb exp(obs) depending on assumed Higgs to diphoton branching ratio


Top
hierarchy
Higgs
New Physics
naturalness
Composite Higgs

NEW PHYSICS REQUIRED

- The large mass of the top quark induces large quadratic divergencies
- Solutions to the problem involve hypothesizing the existence of top partners of bosonic (SUSY) or fermionic (Little/Composite Higgs, Extra Dimensions) nature, that automatically cancel out such divergencies
- In both scenario, several additional particles appear, providing a very rich phenomenology



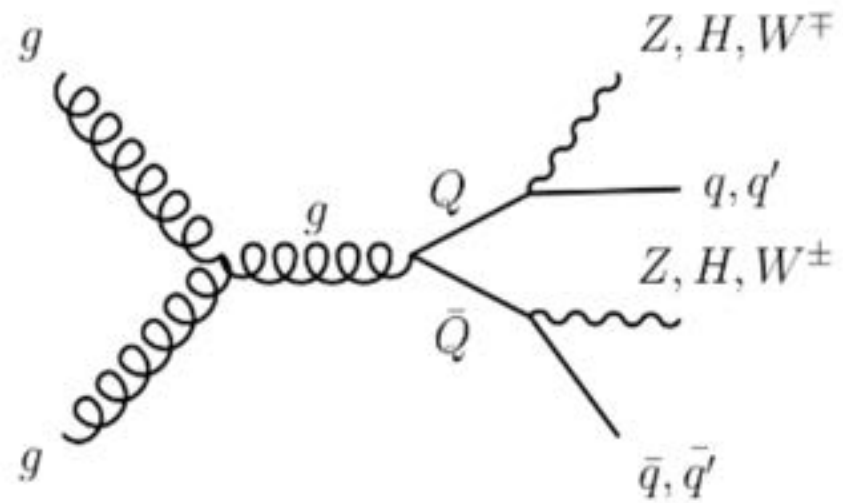
— Light (<2TeV) Top Partners are present in any « reasonably Natural » model, i.e. less than one order of magnitude cancellation

— Heavier (<10TeV) Resonances needed

— The new LHC energy opens up the discovery reach for this very interesting mass region

Fermionic top partners

- Fourth generation replica of SM quarks strongly disfavored by Higgs data

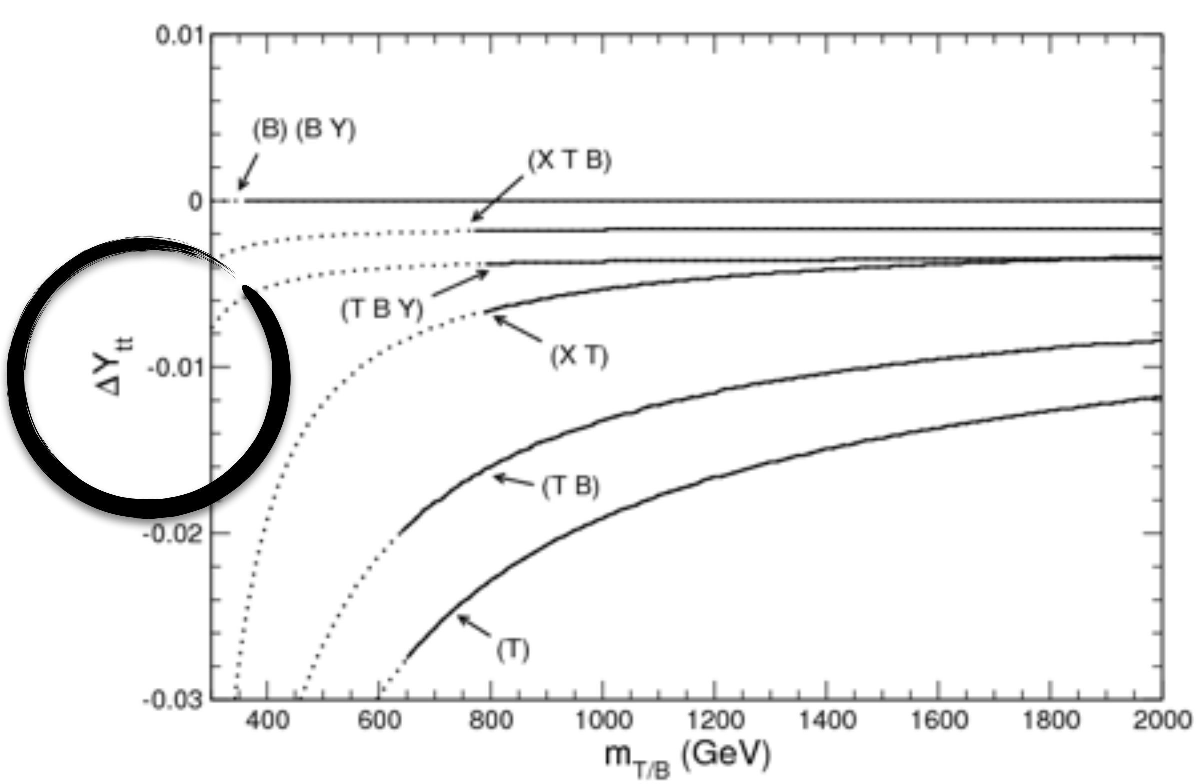


Singlets	Doublets	Triplets
$\mathbf{1}_{2/3} = T$	$\mathbf{2}_{1/6} = \begin{pmatrix} T \\ B \end{pmatrix}$	$\mathbf{3}_{2/3} = \begin{pmatrix} X \\ T \\ B \end{pmatrix}$
	$\mathbf{2}_{7/6} = \begin{pmatrix} X \\ T \end{pmatrix}$	
$\mathbf{1}_{-1/3} = B$	$\mathbf{2}_{-5/6} = \begin{pmatrix} B \\ Y \end{pmatrix}$	$\mathbf{3}_{-1/3} = \begin{pmatrix} T \\ B \\ Y \end{pmatrix}$

Notation:

Isospin$_{\text{Hypercharge}}$

$T \to +2/3$
$B \to -1/3$
$X \to +5/3$
$Y \to -4/3$
} Electric charge

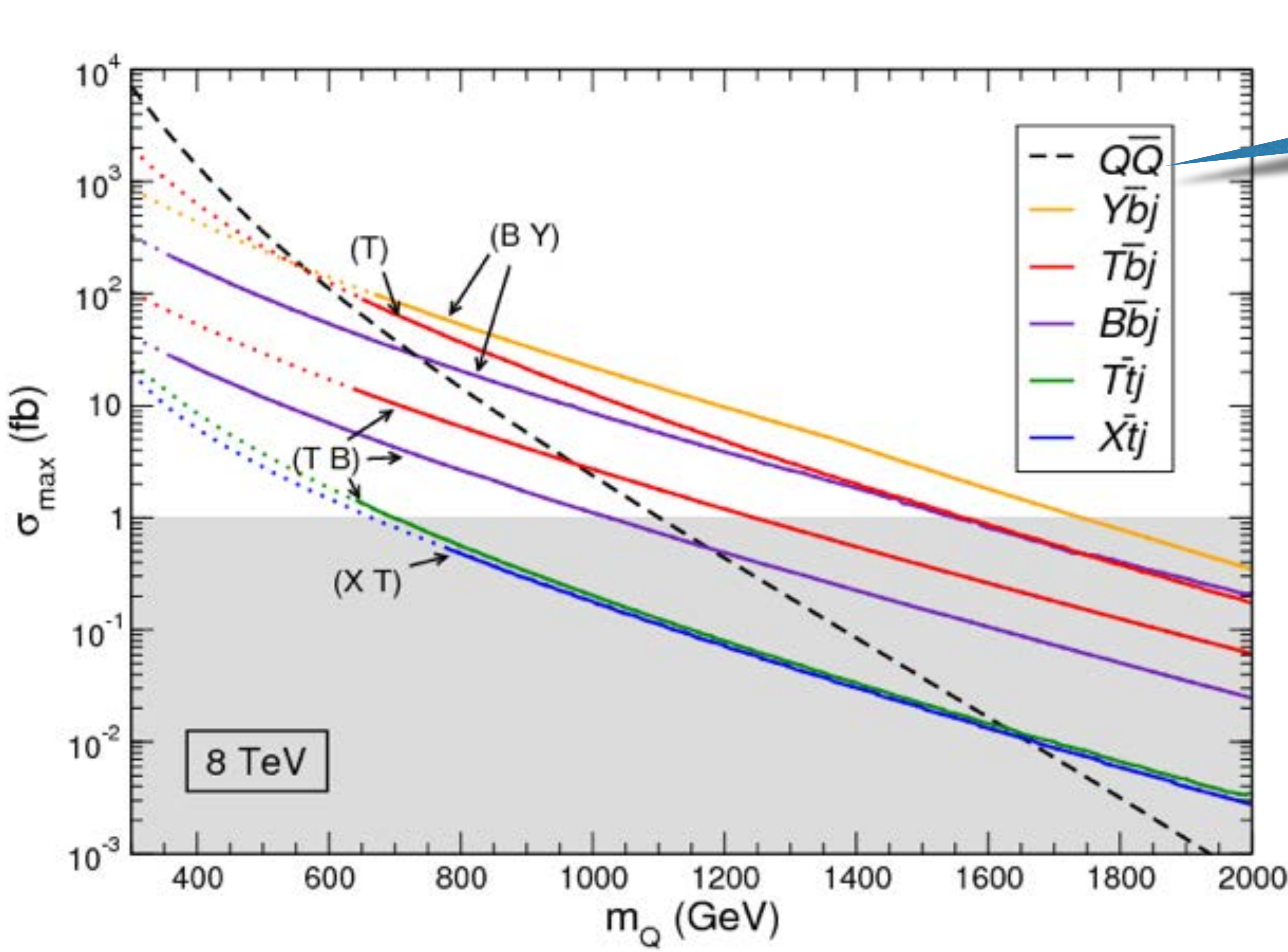


- Vector-like quarks not not acquire mass due to Yukawa coupling
- Deviation from top Yukawa too small to be visible, both in current and future collider experiments

J.A. Aguilar-Saavedra, R. Benbrik, S. Heinemeyer, M. Pérez-Victoria
arXiv:1306.0572

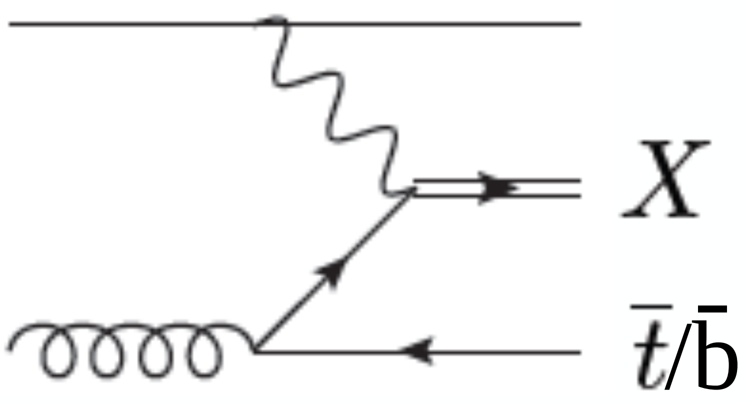
Fermionic top partners

- Pair production is a QCD process: only free parameter is the new particle mass



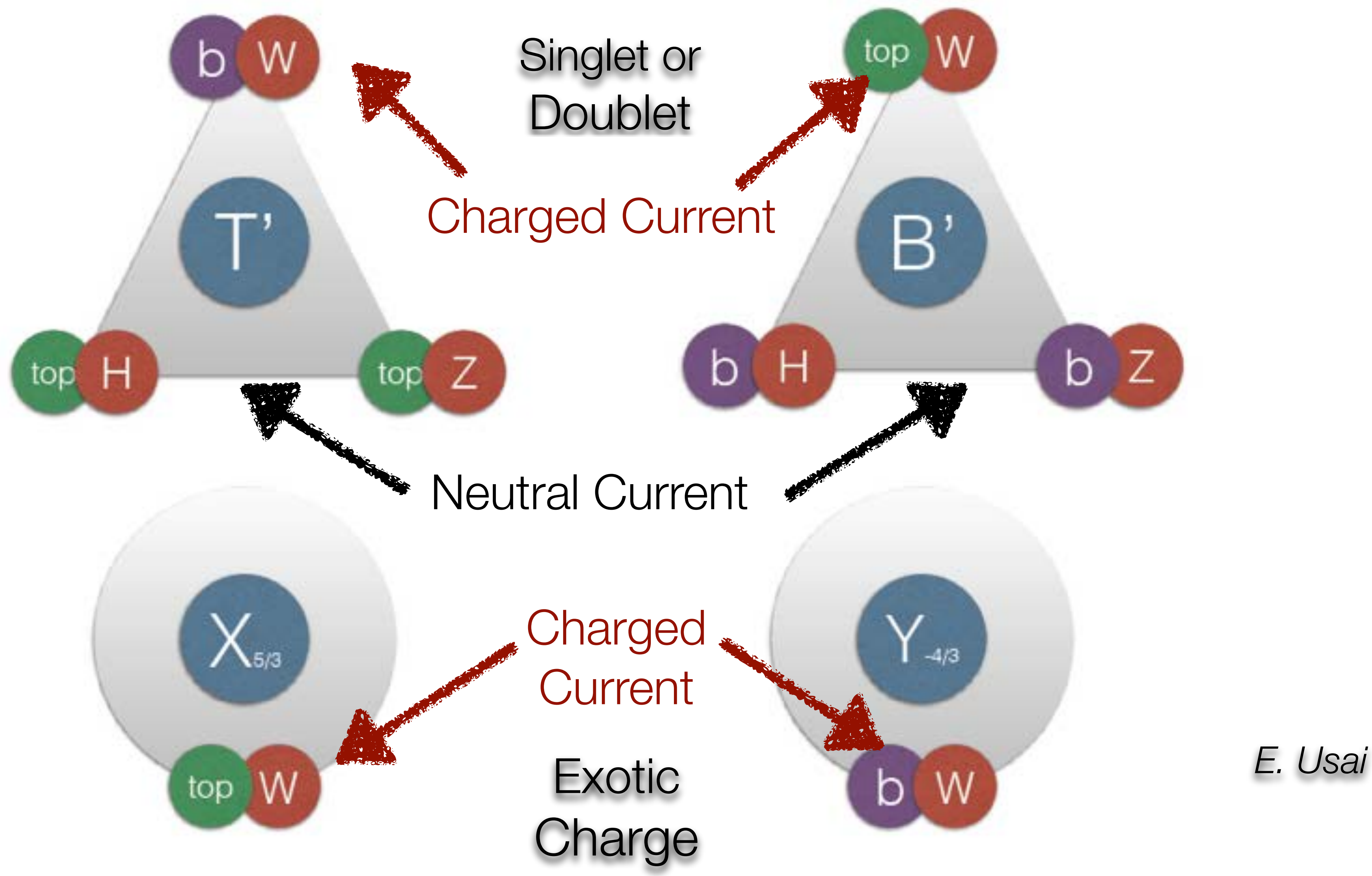
J.A. Aguilar-Saavedra, R. Benbrik, S. Heinemeyer, M. Pérez-Victoria
arXiv:1306.0572

- single production depends on the model



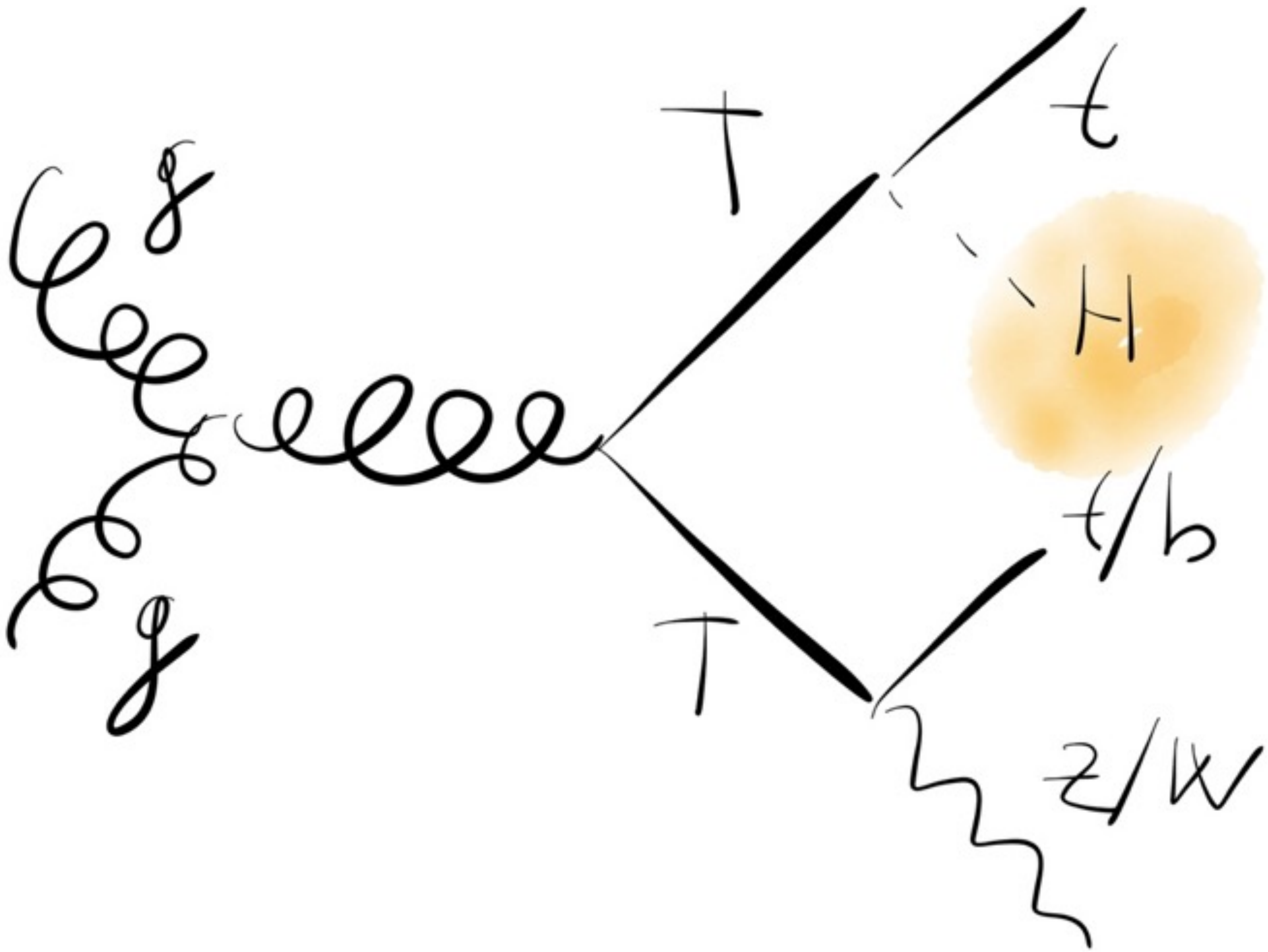
- single production will be key in the new run

Decay modes at a glance (for 3rd generation only)



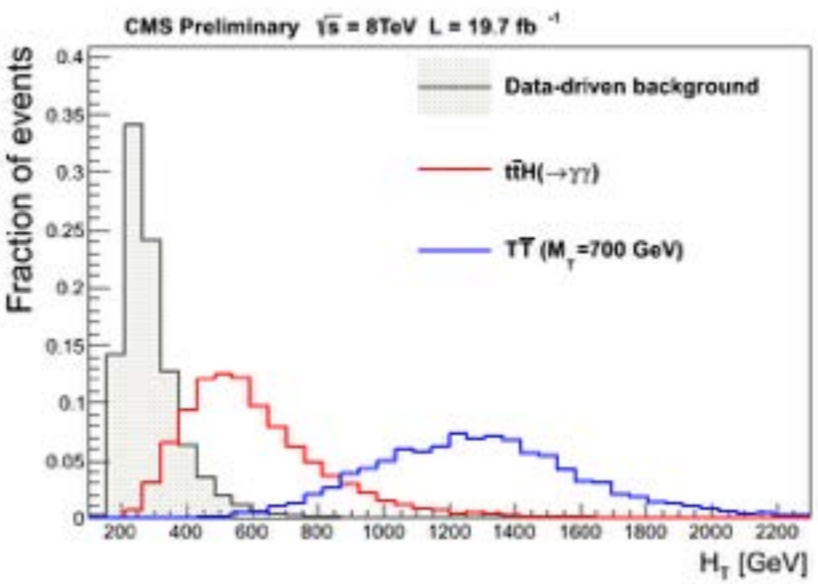
The exact branching ratios are model dependent, need to explore all of the above

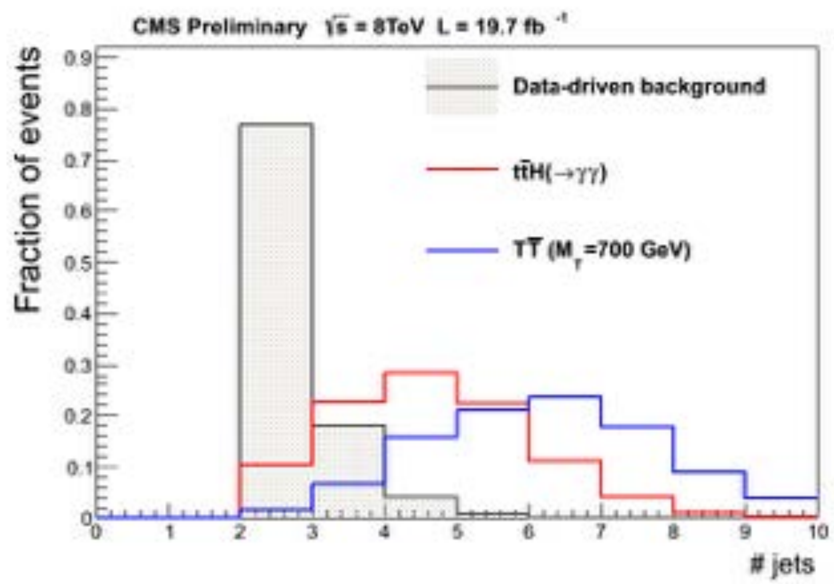
Fermionic top partners



*example diagram

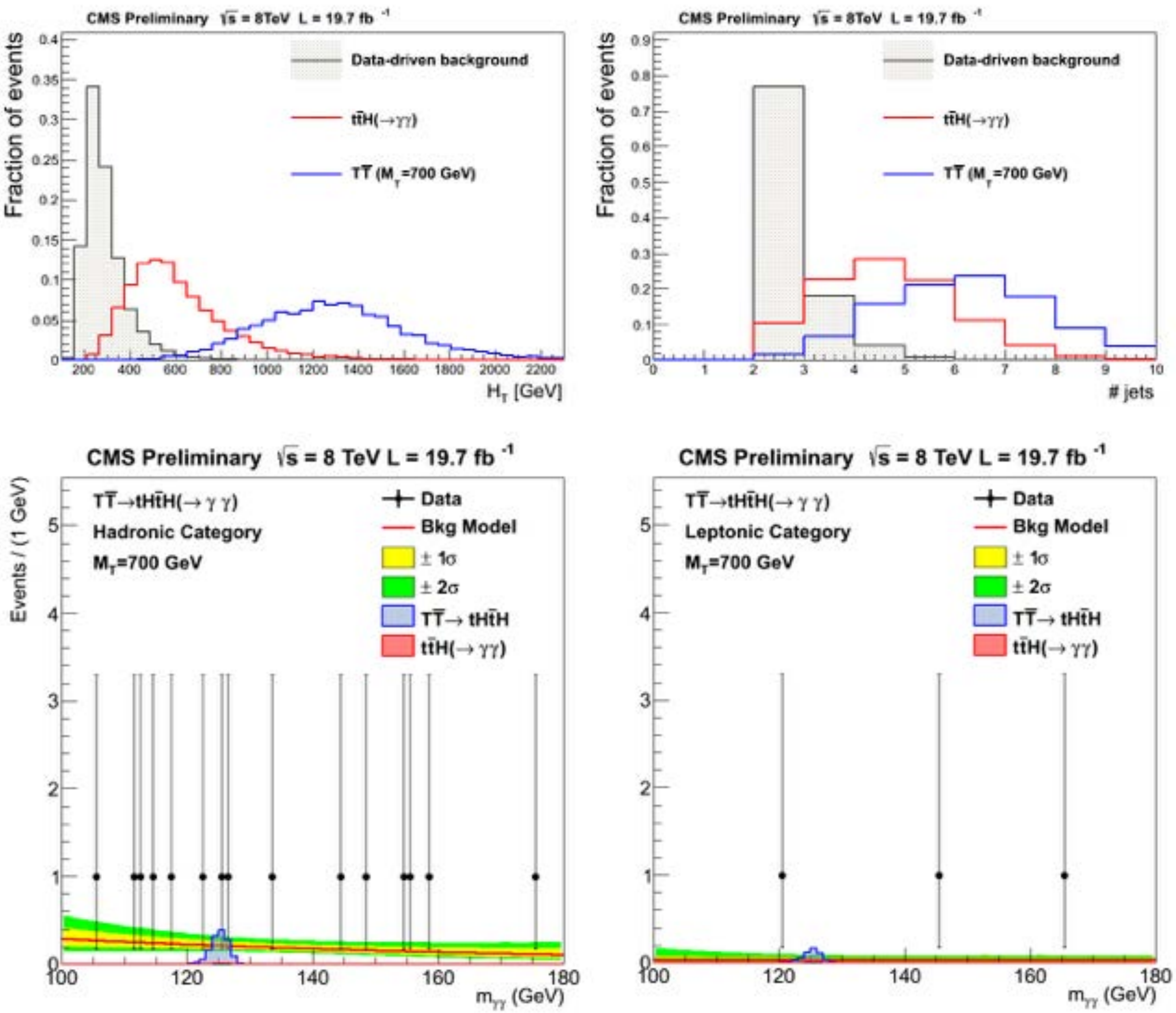
Fermionic top partners





- Focus on the T→tH decay chain is particularly relevant
- Here H→γγ

FERMIONIC TOP PARTNERS



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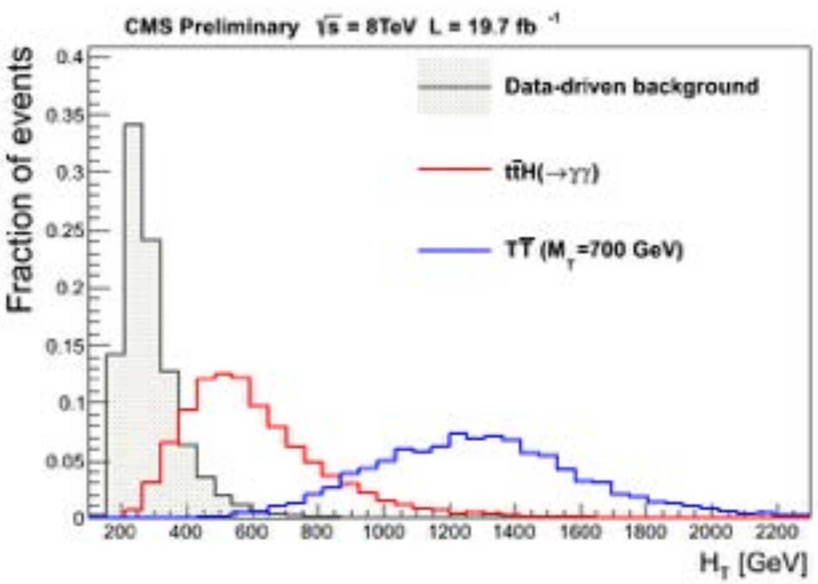
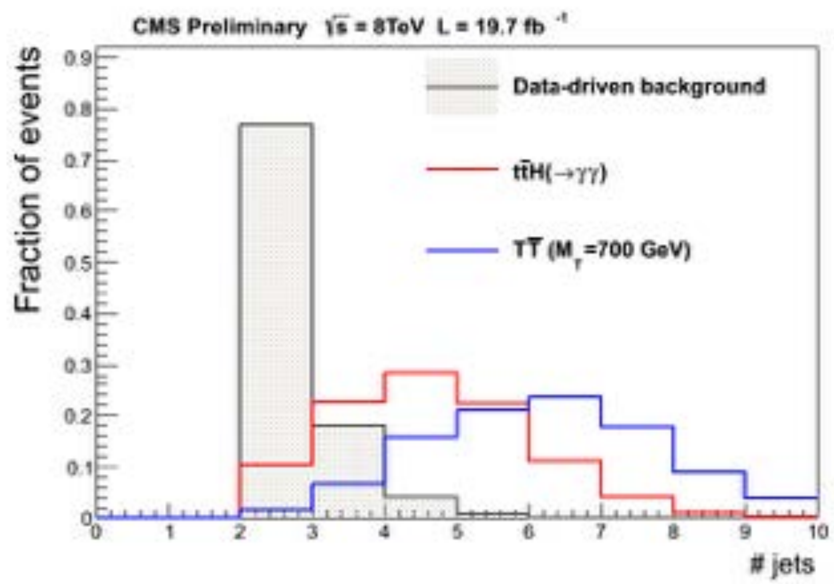
Fermionic top partners





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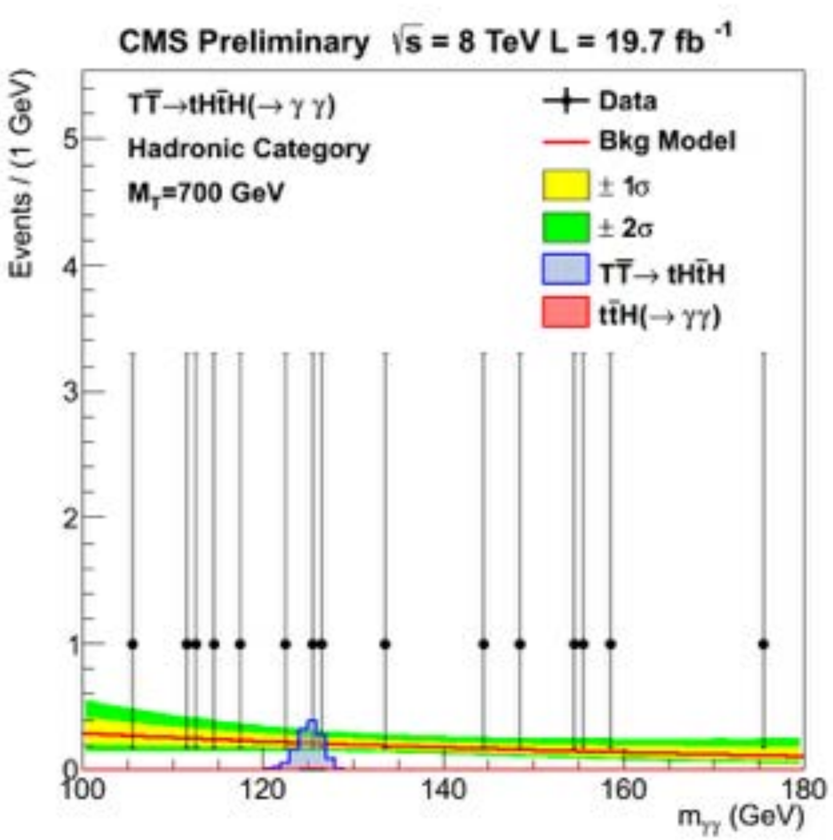
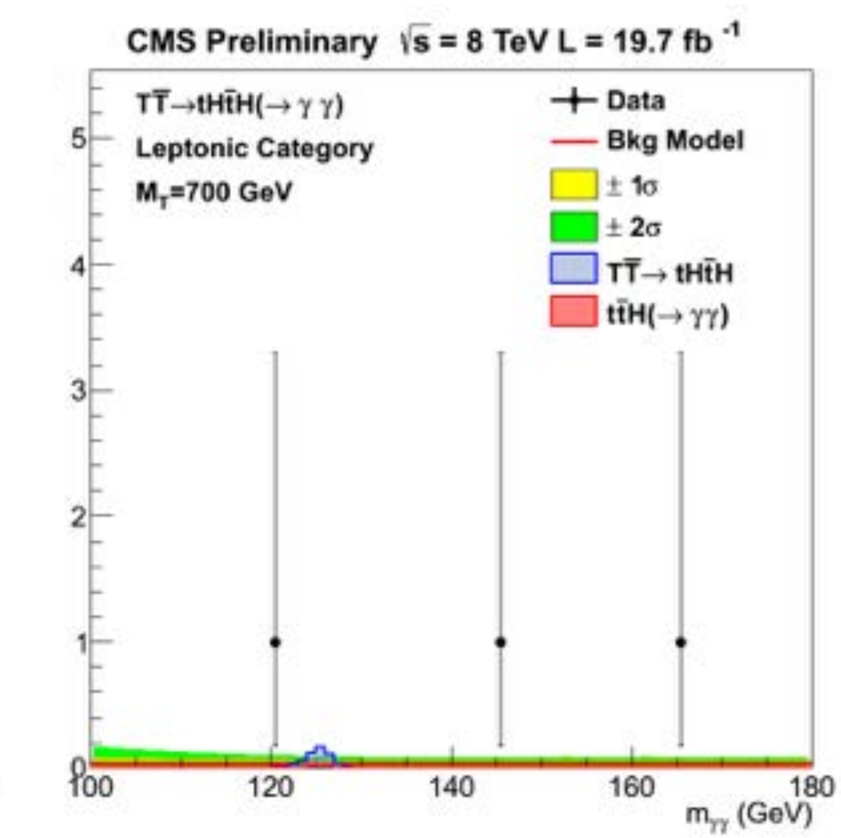
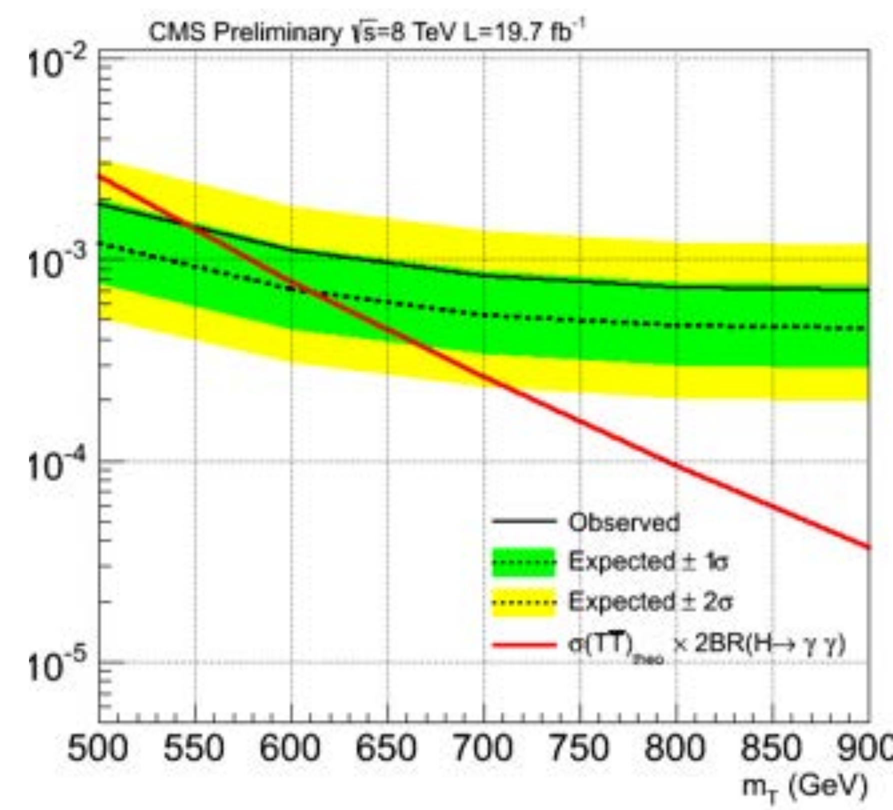
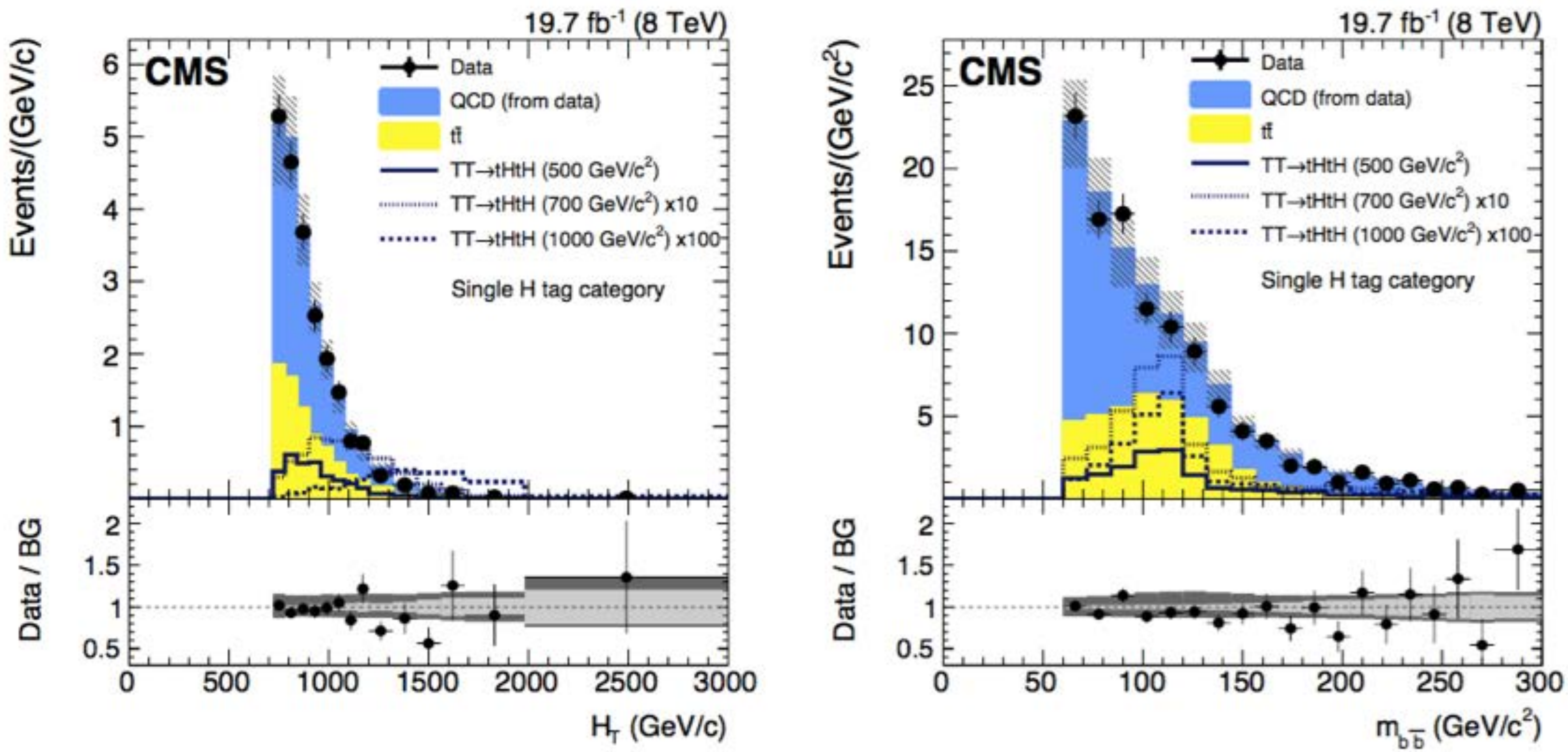






FERMIONIC TOP PARTNERS

- Take any possible final state, using any possible number/flavor of leptons, number of b-tags, identified boosted bosons. In particular:
  - all-hadronic T→tH
  - all-hadronic T→tW

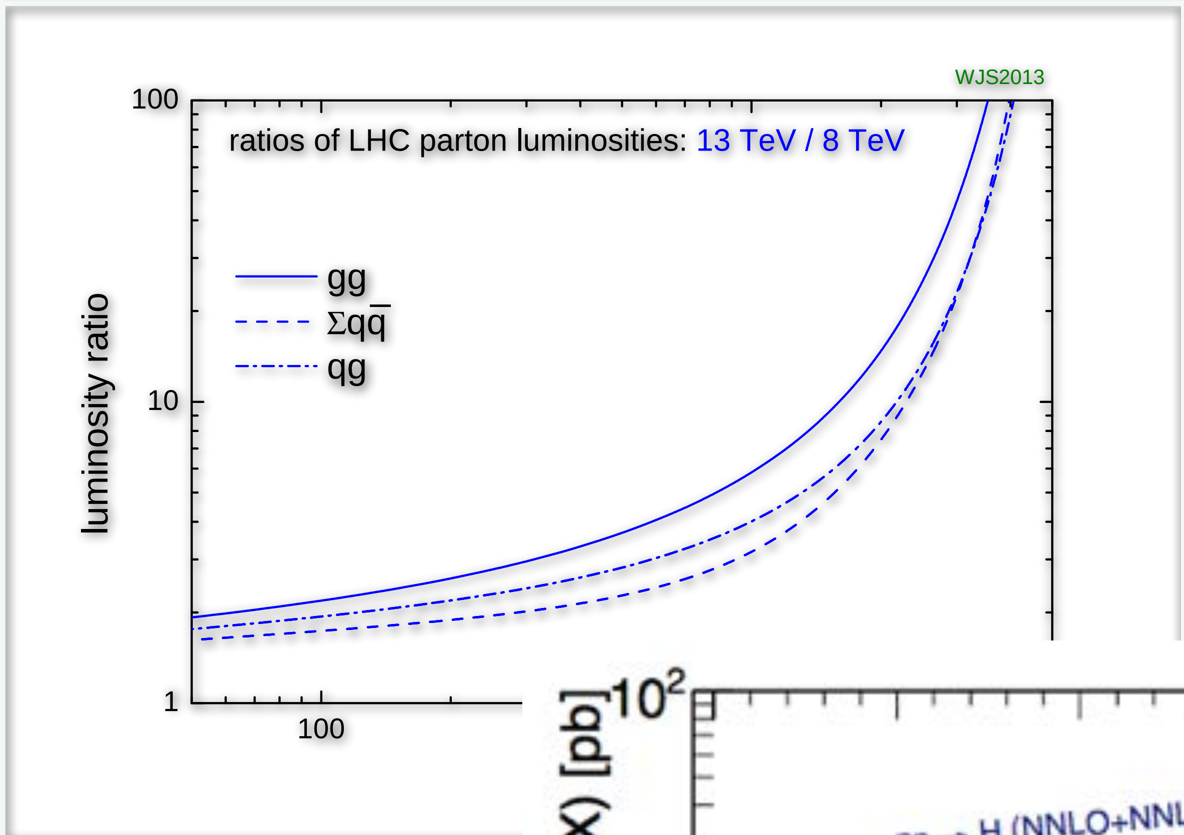


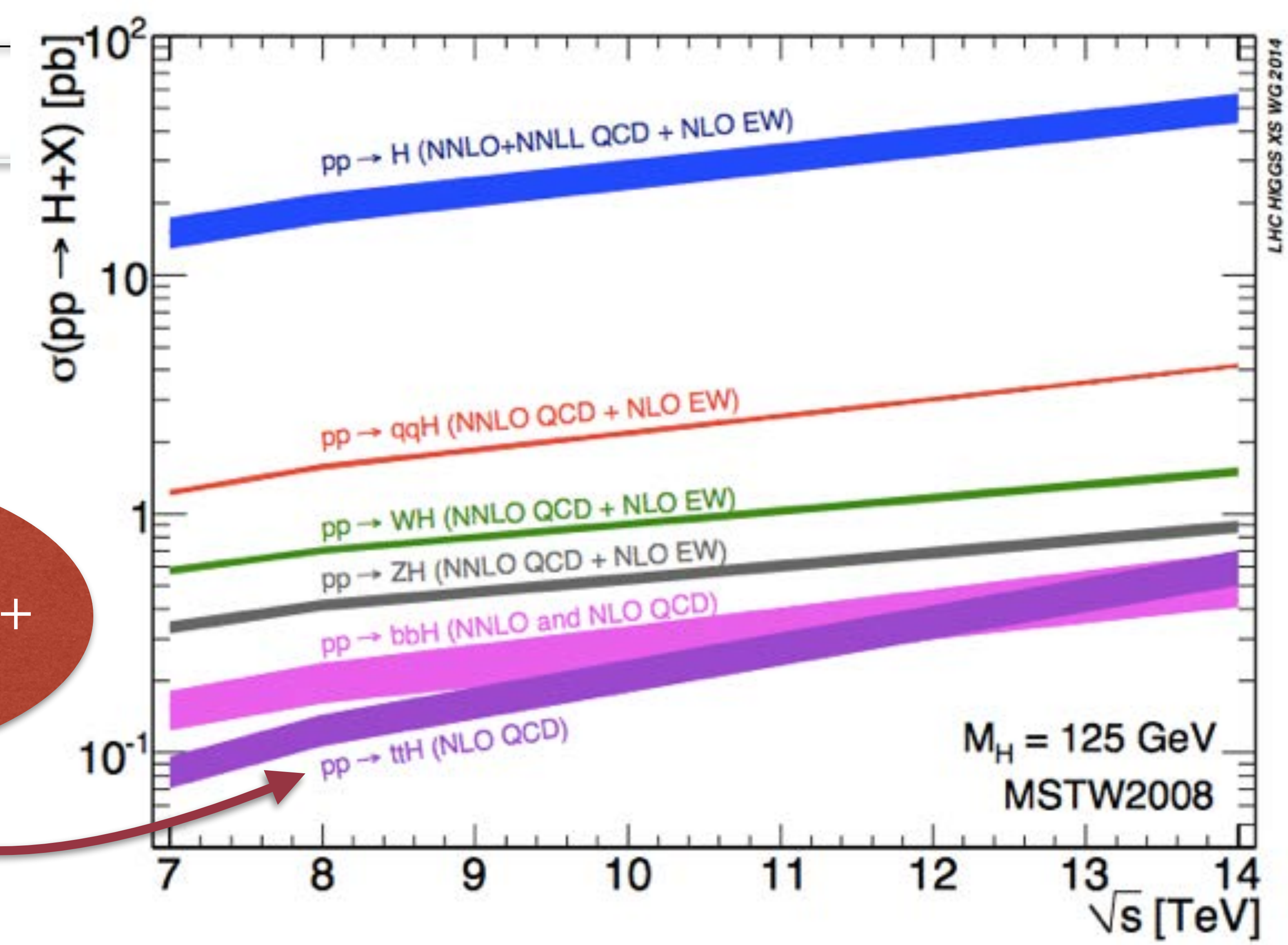
- Limits on T→qV hyp. ranging in the 700-800GeV range: arXiv:1509.04177

LIFE GETS BETTER AT 13TEV

New energy:

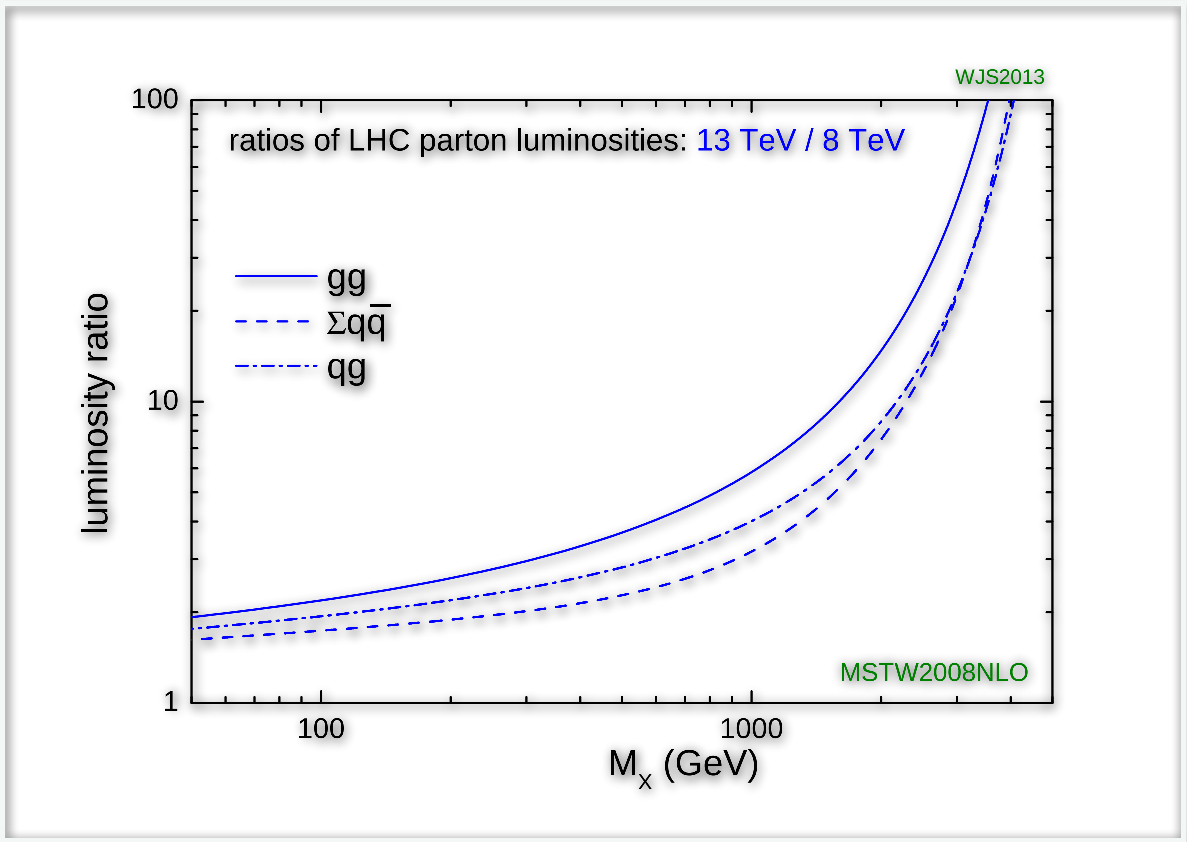
- increased parton luminosities, increased mass reach for less luminosity
- this is especially true for heavy quarks
- single heavy quark will become more important
- challenge: keep/improve performance wrt Run1





Fastest rise! And same for single top + Higgs

Life gets better at 13TeV



New energy:

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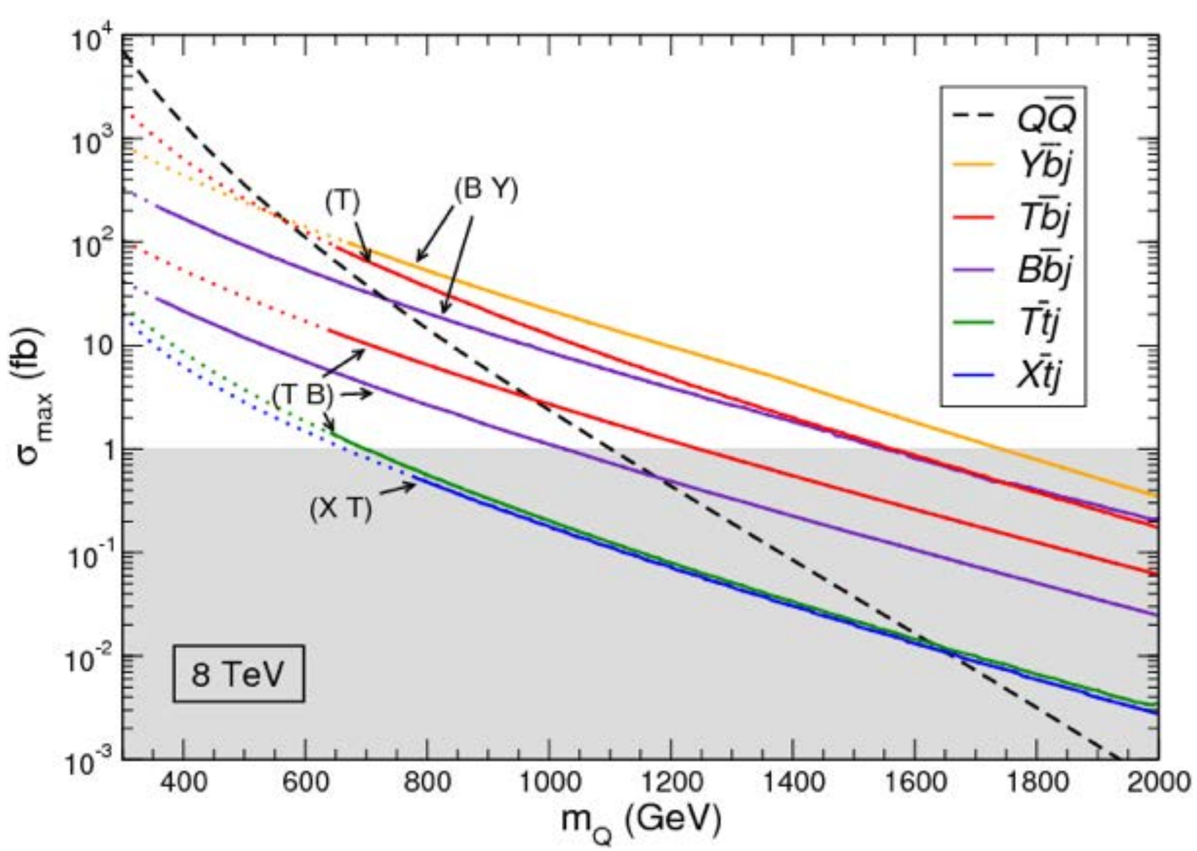
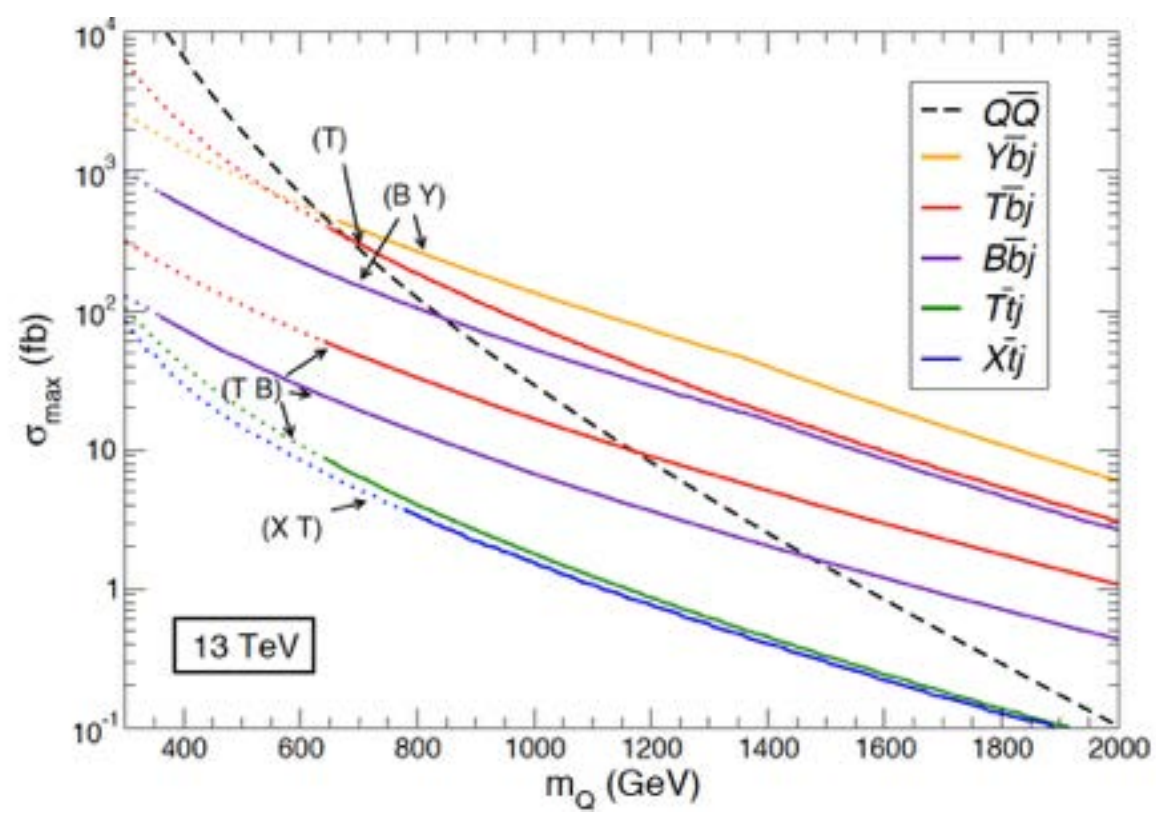
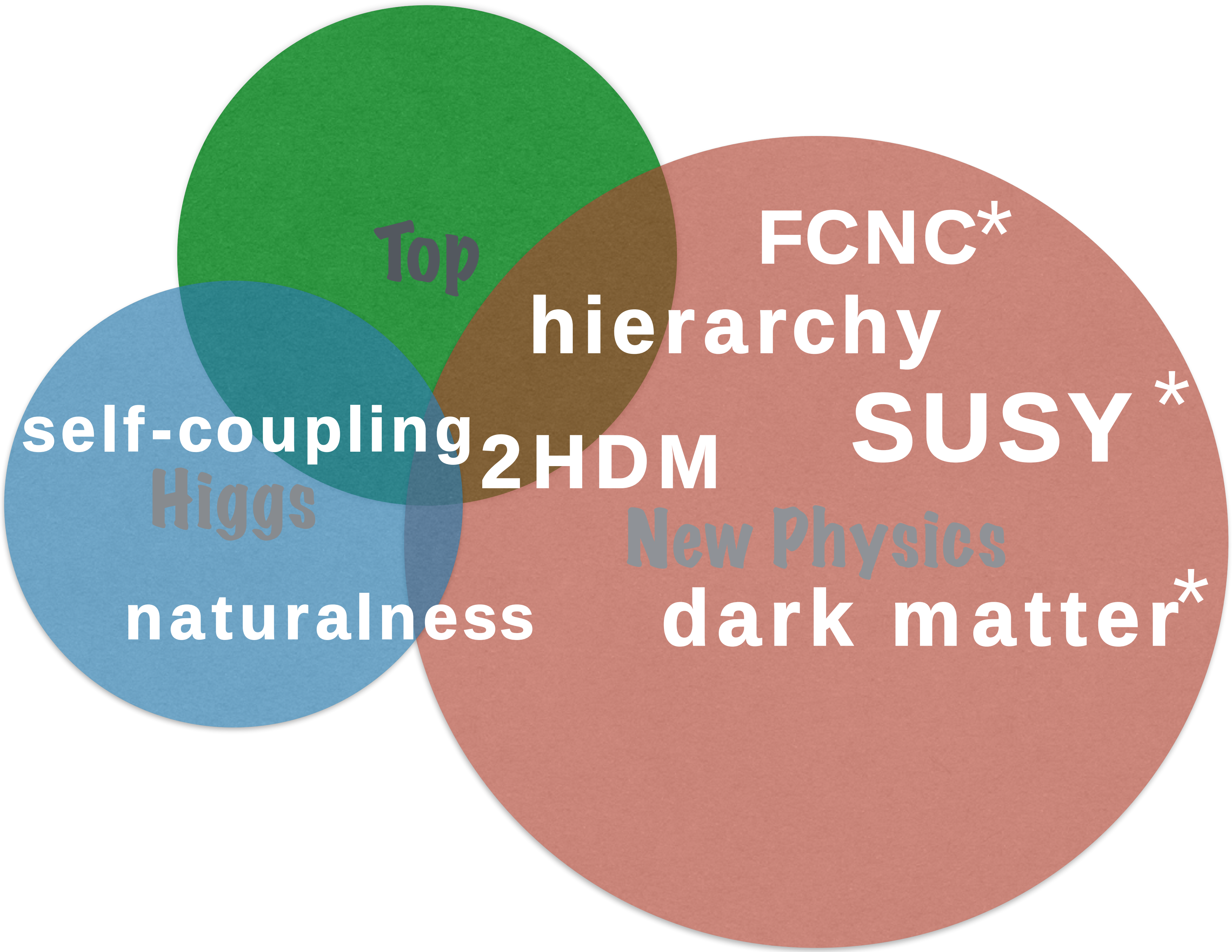
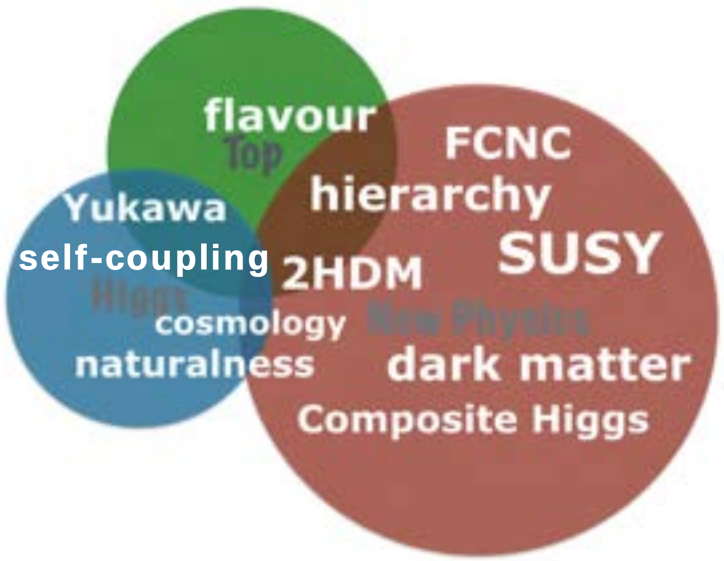






*not shown here



- Each way to probe top-Higgs has his own th+exp. advantages/disadvantages - CMS is developing a *strong, synergic effort* to exploit different production and decay modes
- *Direct exploration* of top-Higgs coupling will soon allow *independent probe on SM*
- New physics would modify direct Higgs production, ttH, and tH in *different* ways
- New heavy quarks (bosons) with very rich phenomenology could very much lie only a few months of data-taking away

20 years ago

20 years ago

Top

20 years ago


Researchers announce 'top quark' discovery
Cultura e Spettacoli
Dove vai, cacciatore di quark?
Top
Batavia is center of universe
Alles Quark, oder was?
I predatori del quark perduto
Truth by Consensus
Nation
physicists, last piece of a puzzle
RICERCA ITALIANA
EPPUR SI MUOVE

20 years ago

3 years ago

Higgs

20 years ago

3 years ago

Top

20 years ago

3 years ago

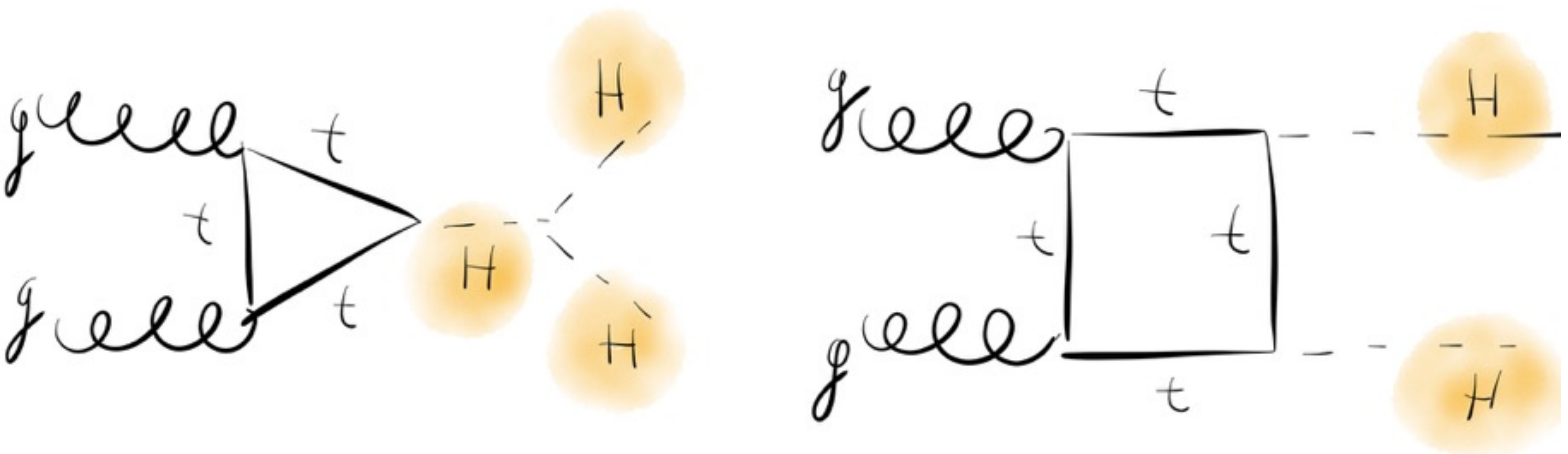

PARTICLEFEVER^2
WITH ONE SWITCH, EVERYTHING CHANGES AGAIN
COMING SOON
Top
New Physics
Higgs

Thanks!!!


PARTICLEFEVER^2
WITH ONE SWITCH, EVERYTHING CHANGES AGAIN
COMING SOON
Top
New Physics
Higgs

BACKUP

HIGGS SELF-COUPLING

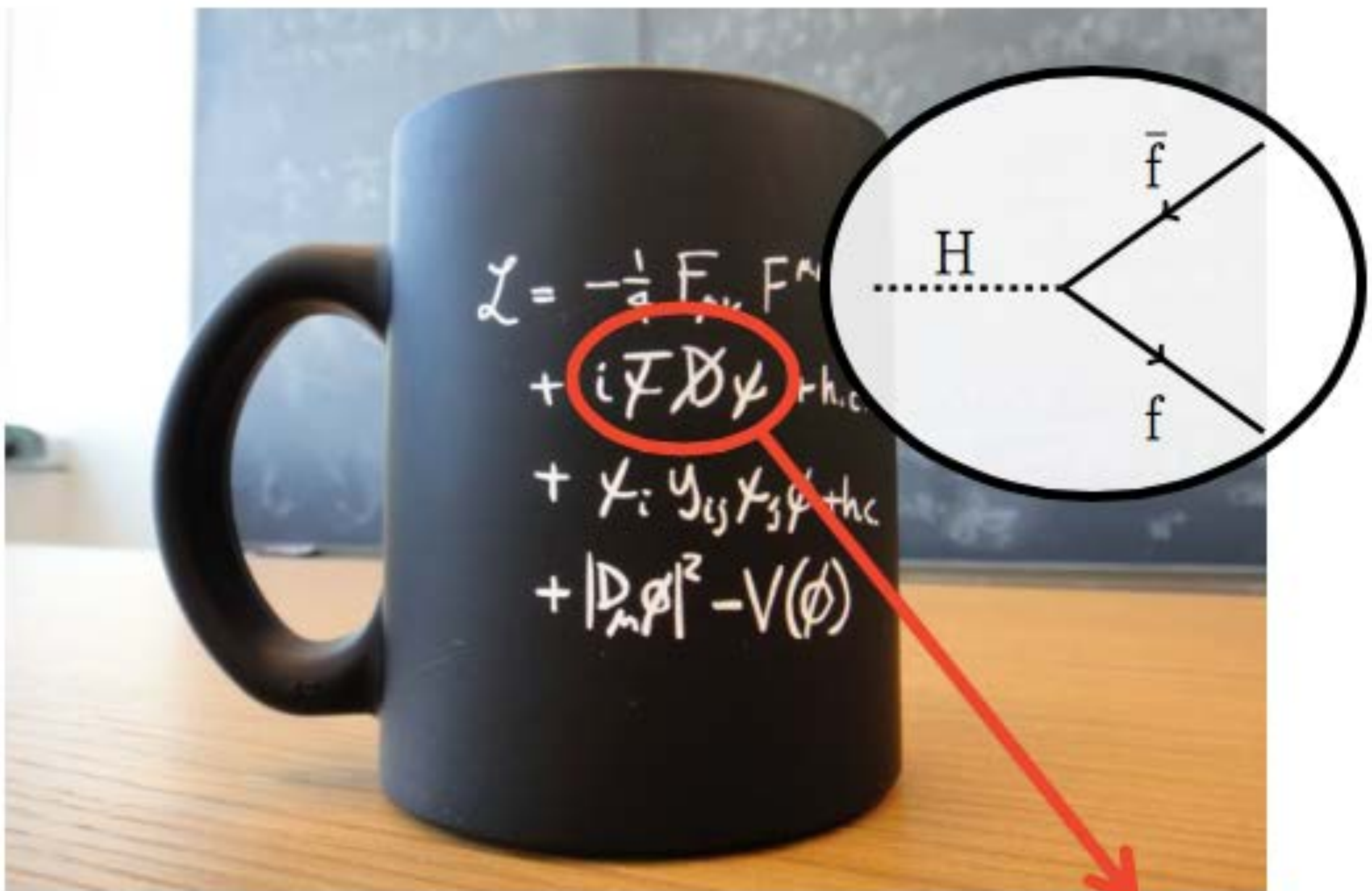


CMS@WORK

Final state topology	Possible channels
All-hadronic with boosted top and boosted Higgs	**Single VLQ**: T'->tH
Lepton + b-jet	**Single VLQ**: Y4/3 -> bW, T' ->bW
Opposite-sign di-leptons and jets	**Single VLQ**: B' -> bZ, T' -> tZ
same-sign dileptons	**Single VLQ**: X53->tW, B->tW, T' -> tZ
One lepton, b-jet and boosted Higgs	**Single VLQ** T'->tH, T' -> tZ
One lepton, boosted hadronic top	**Single VLQ**: B'->tW

Final state topology	Possible channels
Di-leptons and boosted hadronic top	**Single VLQ**: T' -> tZ
Multi-b-jet with boosted Higgs	**Single VLQ**: B' -> bH
All-hadronic with b-jet and boosted V tagging	**Single VLQ**: Y4/3 -> bW, T' ->bW
opposite-sign di-leptons and jets (boosted tops, Higgs, and multiple b-jets)	**VLQ pairs**: T'T' -> tZbW, tZtZ, tZtH, (bWbW: TBD), B'B' -> bZbZ, bZbH
inclusive with at least 1 lepton, including W,t and H tagging variables	**VLQ pairs**: T'T' inclusive with leptons
Same-sign di-leptons	**VLQ pairs**: (X5/3X5/3) B'B'->tWtW , T'T'->tZtZ
Single lepton, boosted top, boosted Higgs	**VLQ pairs**: T'T'->tHbW, tHtH, tHtZ;B'B'->bHtW
Single lepton, boosted top, boosted Higgs ?	**VLQ pairs**: T'T' -> inclusive, B'B' -> tWbH, tWbZ, tWtW

YUKAWA



$$y_b \approx 0.02$$

$$y_t \approx 1$$

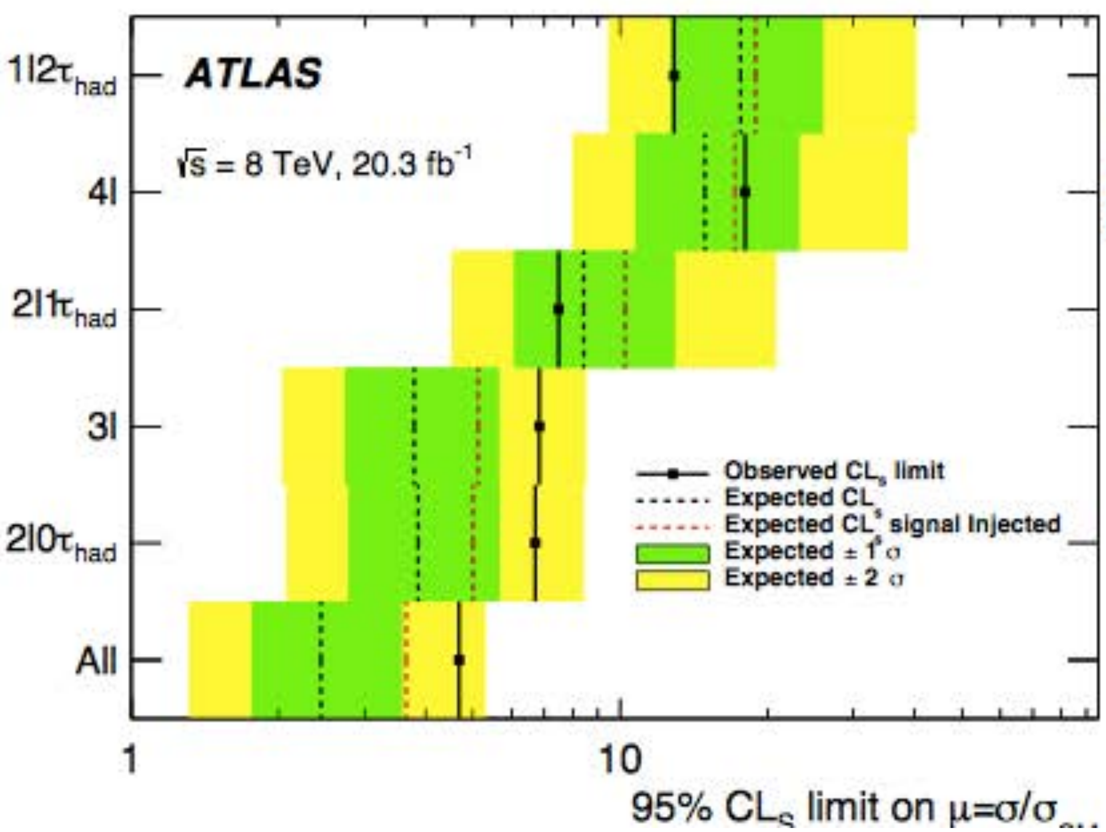
$$m_t = \frac{y_t\ \nu}{\sqrt{2}}$$

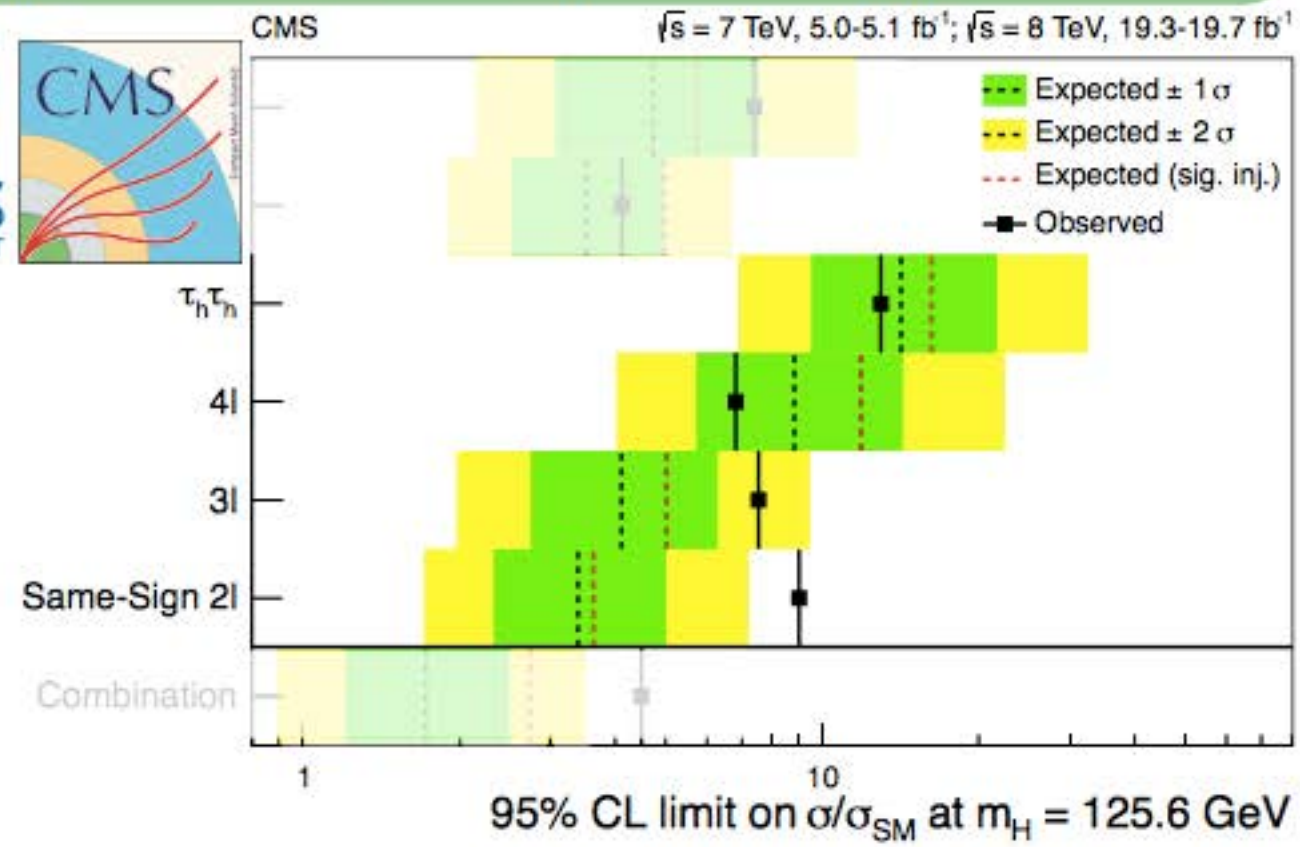
TTH EXCESS: MULTILEPTON

- The results are compatible with the SM expectation, although an excess is observed by both experiments.
- 2ℓ SS and 3ℓ categories are the most sensitive

- The **H→leptons** observed (exp.) **95%CL upper limits on σ/σ_{SM}:**

ATLAS - 4ℓ: 18 (15^{+8}_{-4})	CMS - 4ℓ: 6.8 $(8.8^{+1.2}_{-5.5})$
3ℓ: 6.8 $(3.8^{+1.9}_{-1.1})$	3ℓ: 7.5 $(4.1^{+2.2}_{-1.3})$
$2\ell 0\tau_{had}$: 6.7 $(3.9^{+1.8}_{-1.1})$	2ℓ: 9.0 $(3.4^{+1.6}_{-1.1})$



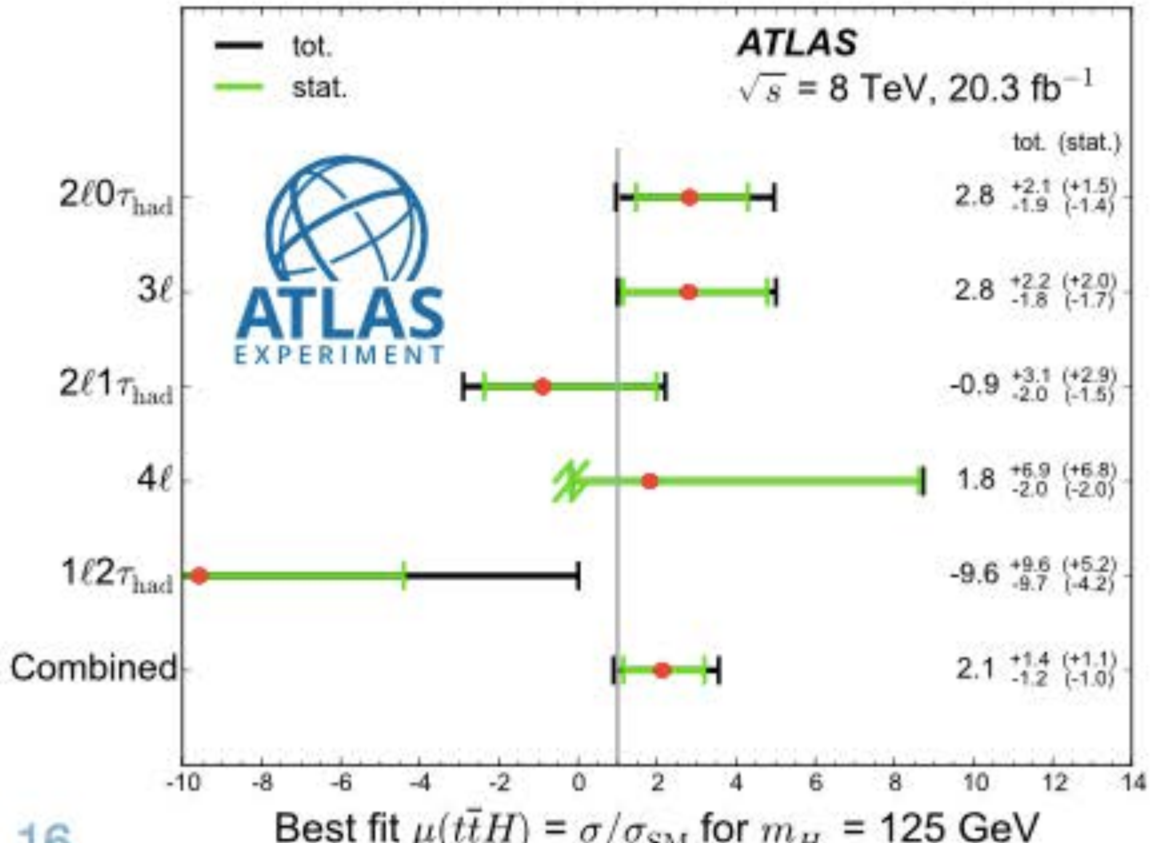


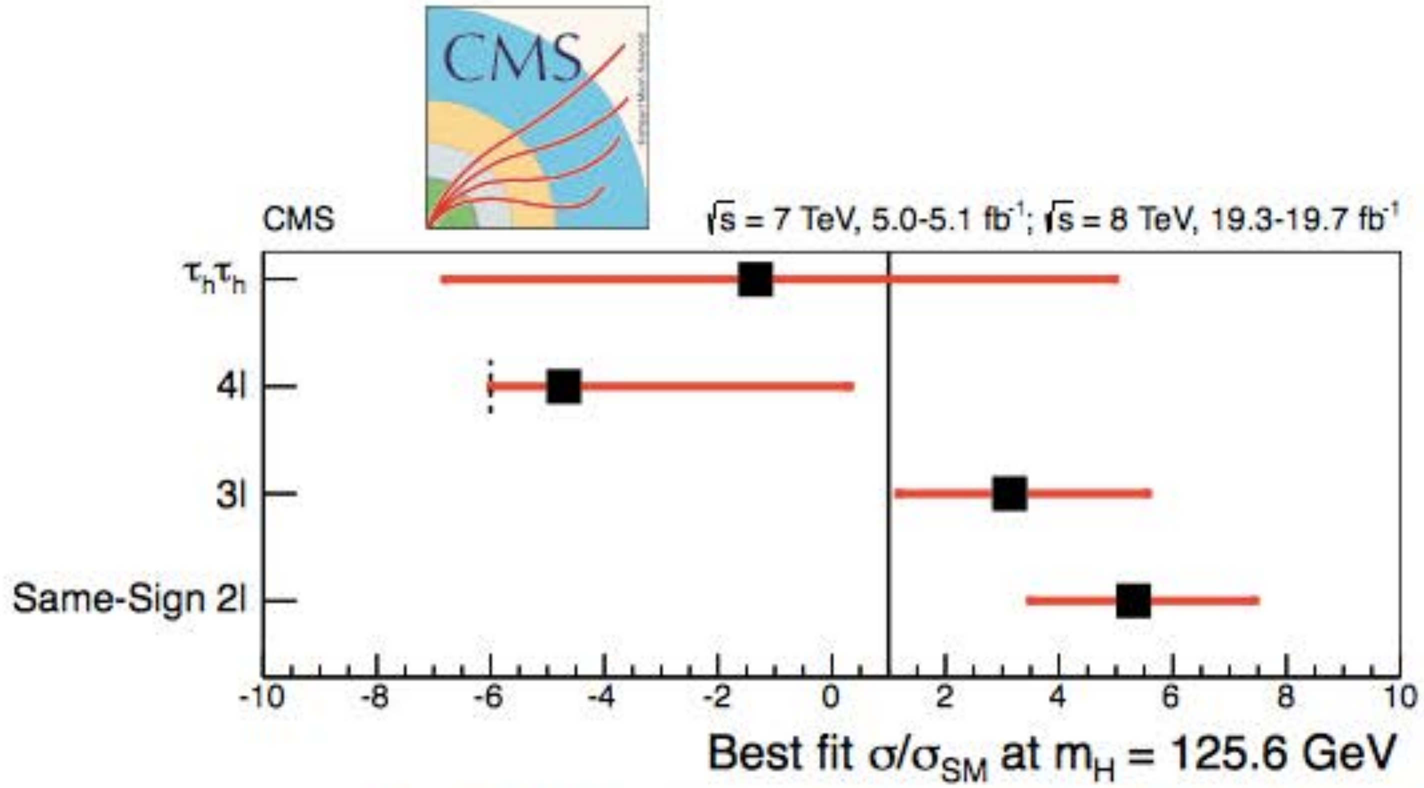
TTH EXCESS: MULTILEPTON

- The results are compatible with the SM expectation, although an excess is observed by both experiments.
- 2ℓ SS and 3ℓ categories are the most sensitive.

- The **H→leptons** observed **best-fit signal strengths**:

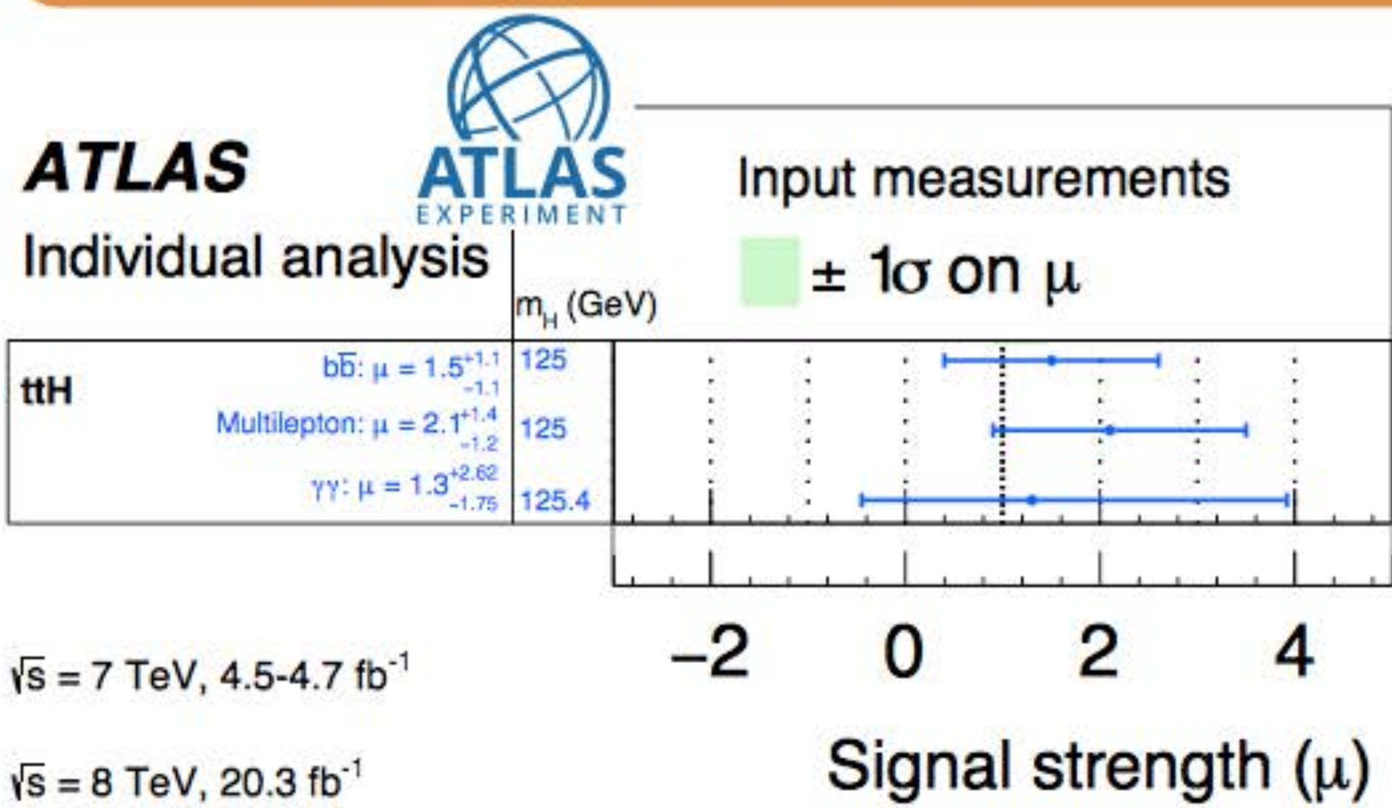
ATLAS		CMS	
ATLAS - 4ℓ:	$1.8^{+6.9}_{-2.0}$	CMS - 4ℓ:	$-4.7^{+5.0}_{-1.3}$
3ℓ:	$2.8^{+2.2}_{-1.8}$	3ℓ:	$3.1^{+2.4}_{-2.0}$
2ℓ0τhad:	$2.8^{+2.1}_{-1.9}$	2ℓ:	$5.3^{+2.1}_{-1.8}$

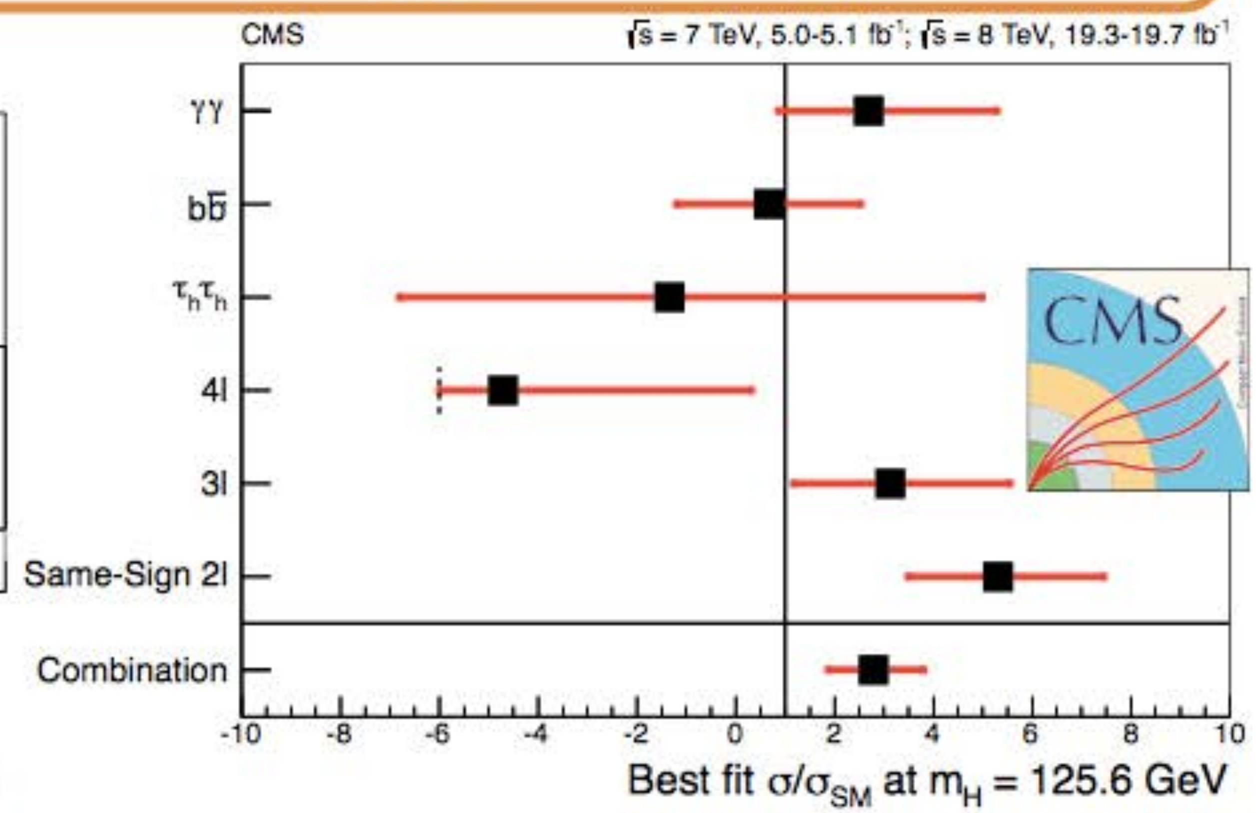


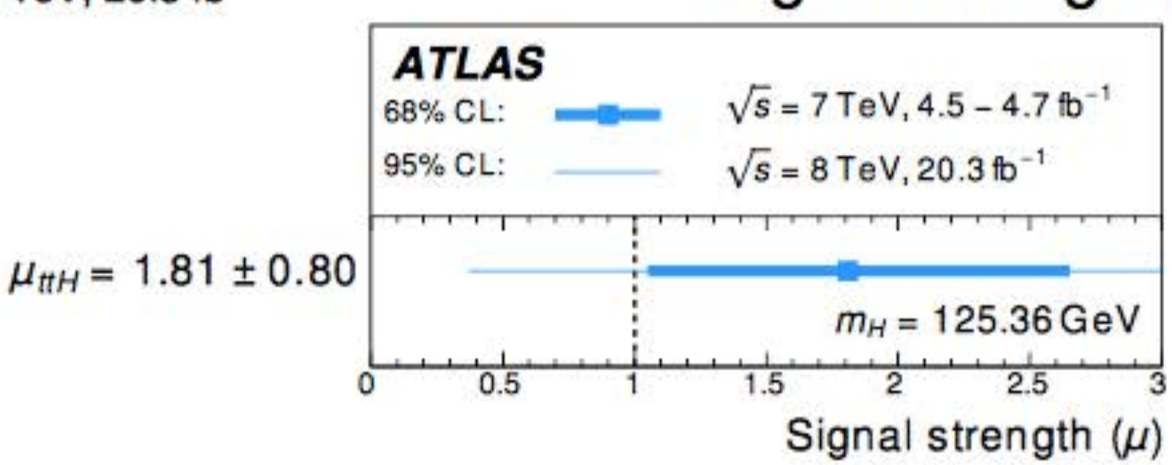


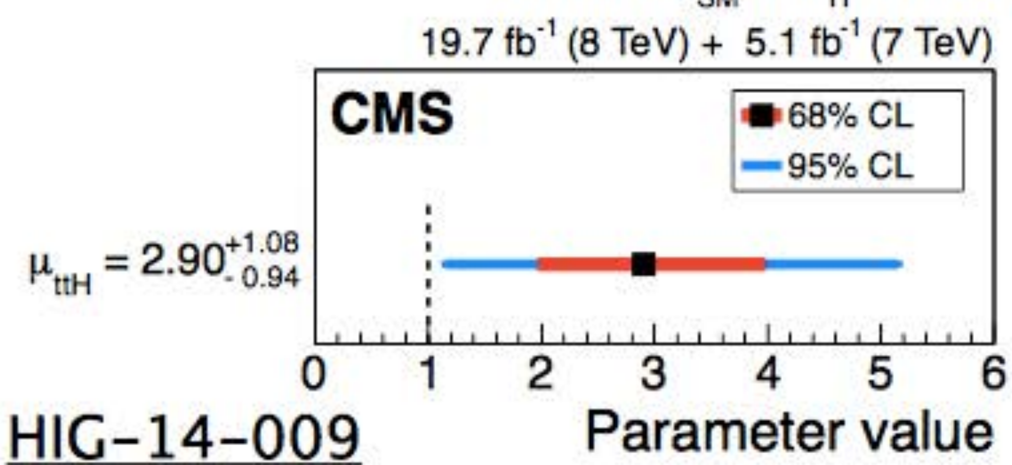
TTH EXCESS: ALL CHANNELS

- The **combined** observed (exp.) **95%CL upper limits on σ/σ_{SM}:**
  ATLAS: 3.2 (1.4) CMS: 4.5 ($1.7^{+0.8}_{-0.5}$)
- The **combined** observed **best-fit signal strengths**:
  ATLAS: $\mu=1.81^{+0.8}_{-0.8}$ CMS: $\mu=2.90^{+1.08}_{-0.94}$



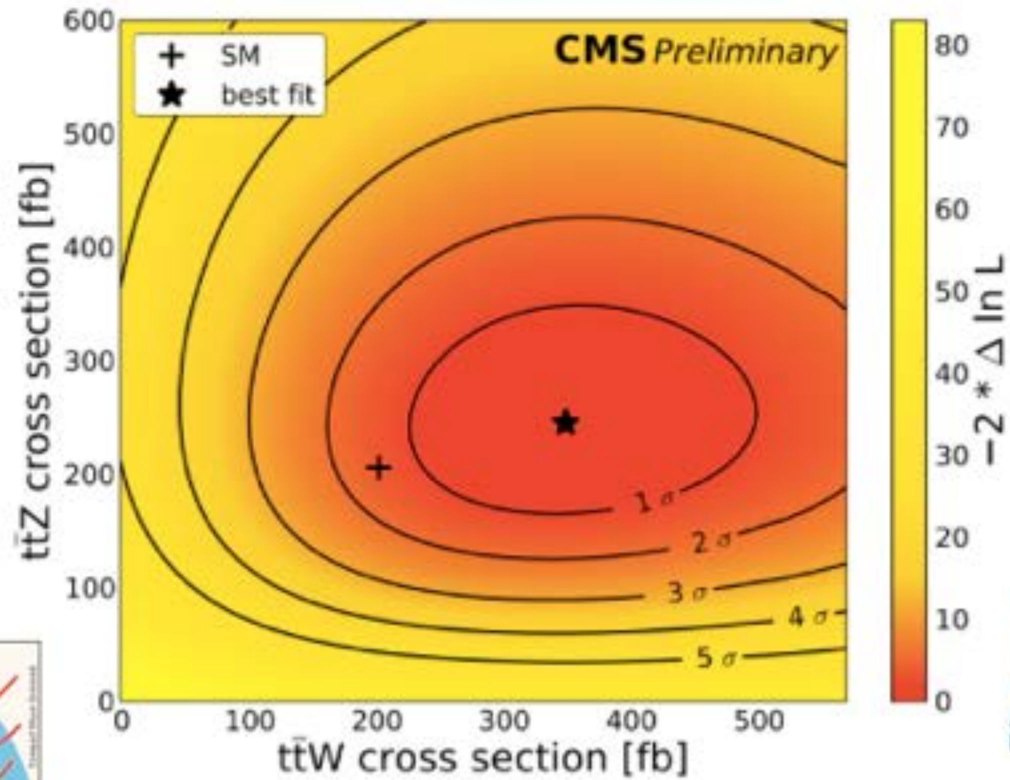




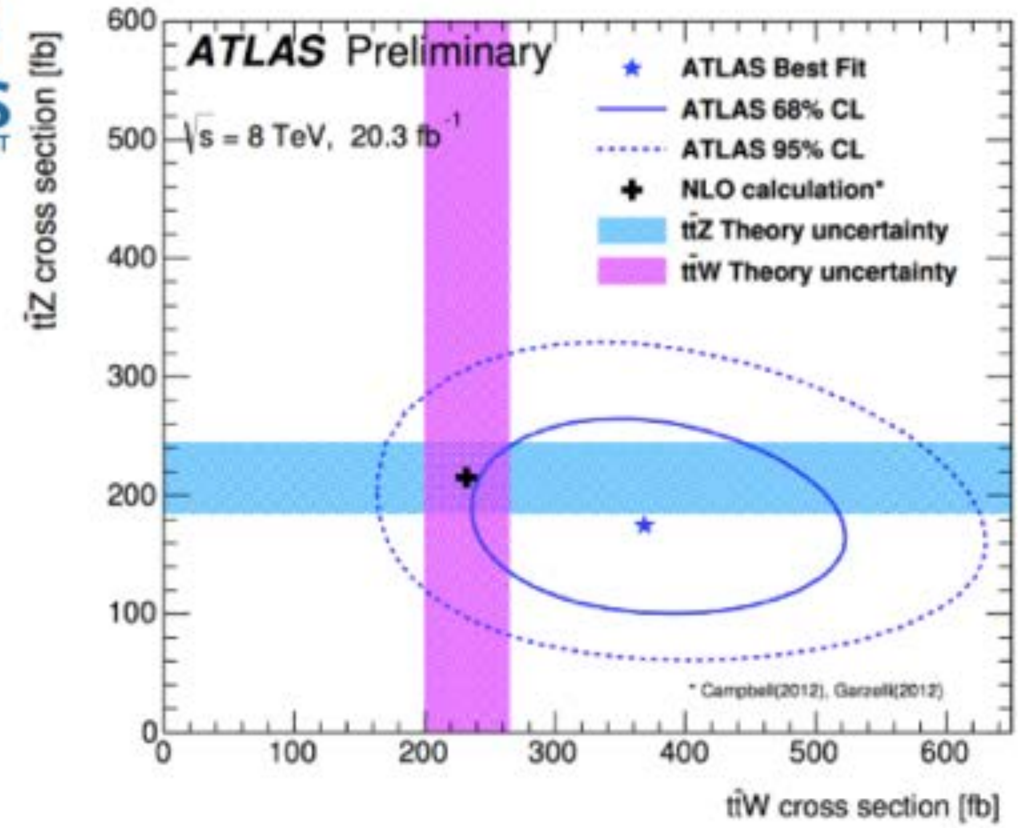


HIG-14-009

TTH OR TTW EXCESS?



Channel	$t\bar{t}W$ significance		$t\bar{t}Z$ significance	
	Expected	Observed	Expected	Observed
2ℓOS	0.4	0.1	1.4	1.1
2ℓSS	2.8	5.0	-	-
3ℓ	1.4	1.0	3.7	3.3
4ℓ	-	-	2.0	2.4
Combined	3.2	5.0	4.5	4.2



$t\bar{t}W$

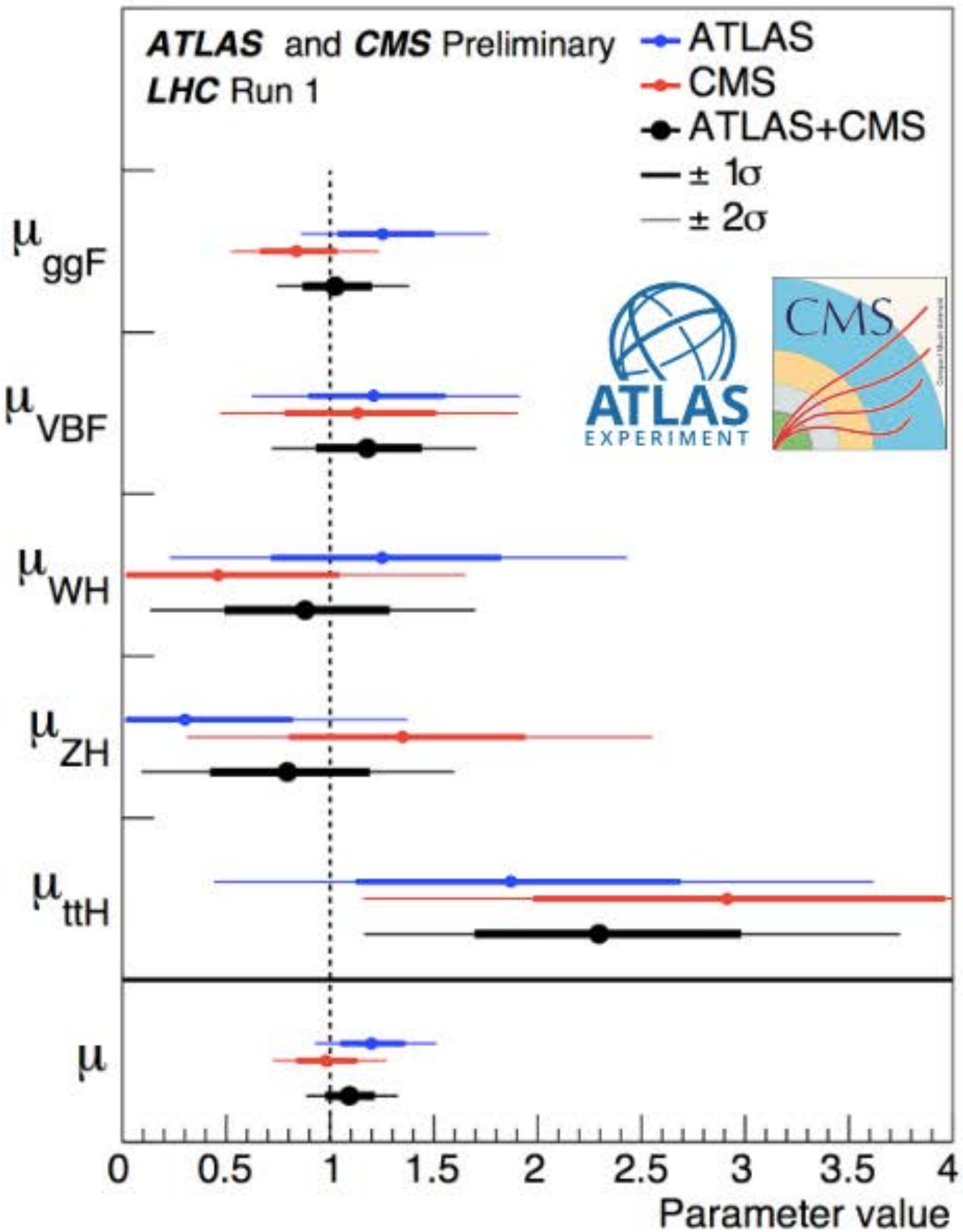
	Cross section (fb)		Signal strength (μ)		Significance	
Channels	Expected	Observed	Expected	Observed	Expected	Observed
SS	203^{+88}_{-73}	414^{+135}_{-112}	$1.0^{+0.45}_{-0.36}$	$2.04^{+0.74}_{-0.61}$	3.4	4.9
3ℓ	203^{+215}_{-194}	210^{+225}_{-203}	$1.0^{+1.09}_{-0.96}$	$1.03^{+1.07}_{-0.99}$	1.0	1.0
SS + 3ℓ	203^{+84}_{-71}	382^{+117}_{-102}	$1.0^{+0.43}_{-0.35}$	$1.88^{+0.66}_{-0.56}$	3.5	4.8

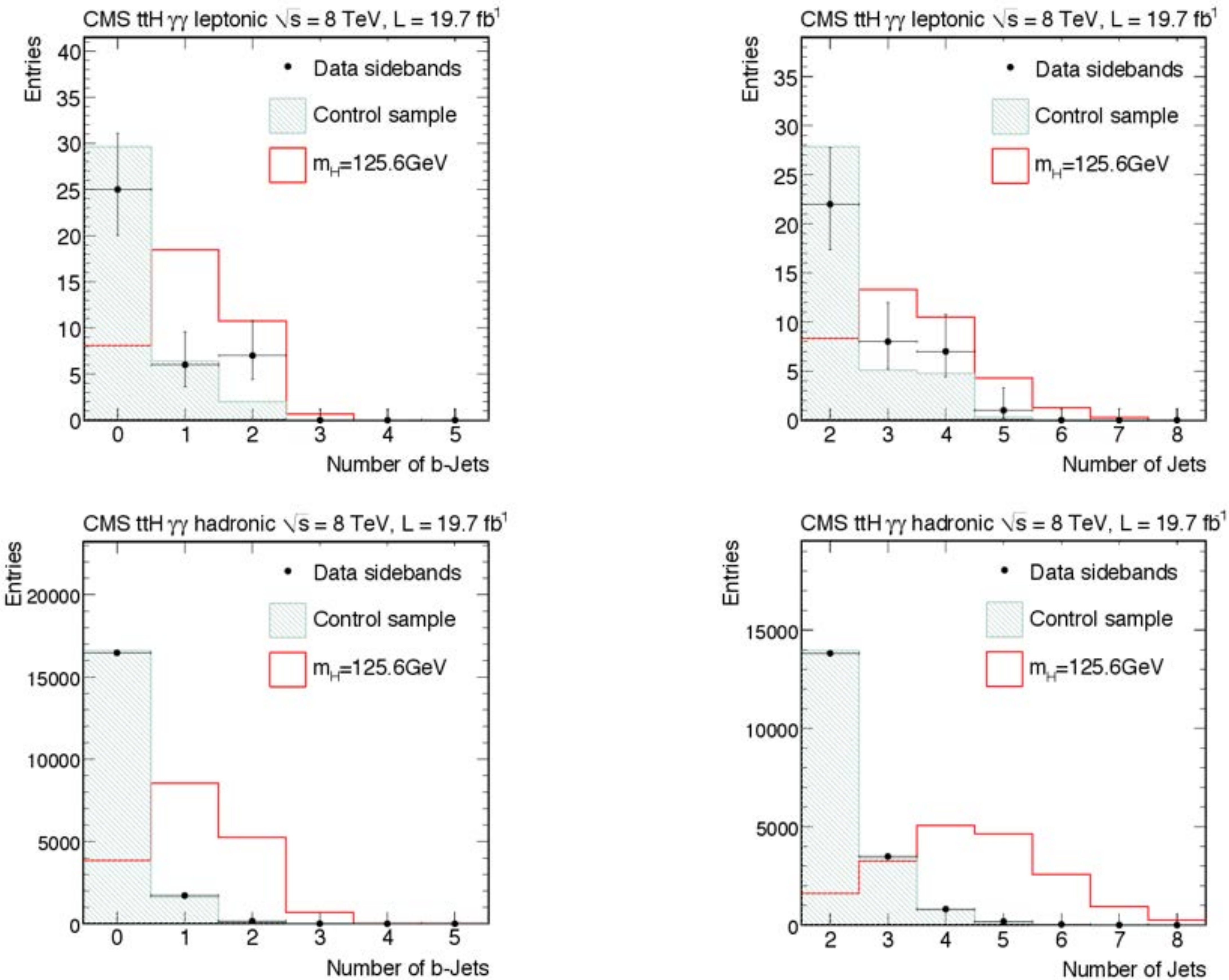
$t\bar{t}Z$

	Cross section (fb)		Signal strength (μ)		Significance	
Channels	Expected	Observed	Expected	Observed	Expected	Observed
OS	206^{+142}_{-118}	257^{+158}_{-129}	$1.0^{+0.72}_{-0.57}$	$1.25^{+0.76}_{-0.62}$	1.8	2.1
3ℓ	206^{+79}_{-63}	257^{+85}_{-67}	$1.0^{+0.42}_{-0.32}$	$1.25^{+0.45}_{-0.36}$	4.6	5.1
4ℓ	206^{+153}_{-109}	228^{+150}_{-107}	$1.0^{+0.77}_{-0.53}$	$1.11^{+0.76}_{-0.52}$	2.7	3.4
OS + 3ℓ + 4ℓ	206^{+62}_{-52}	242^{+65}_{-55}	$1.0^{+0.34}_{-0.27}$	$1.18^{+0.35}_{-0.29}$	5.7	6.4

GLOBAL FIT TO HIGGS COUPLINGS

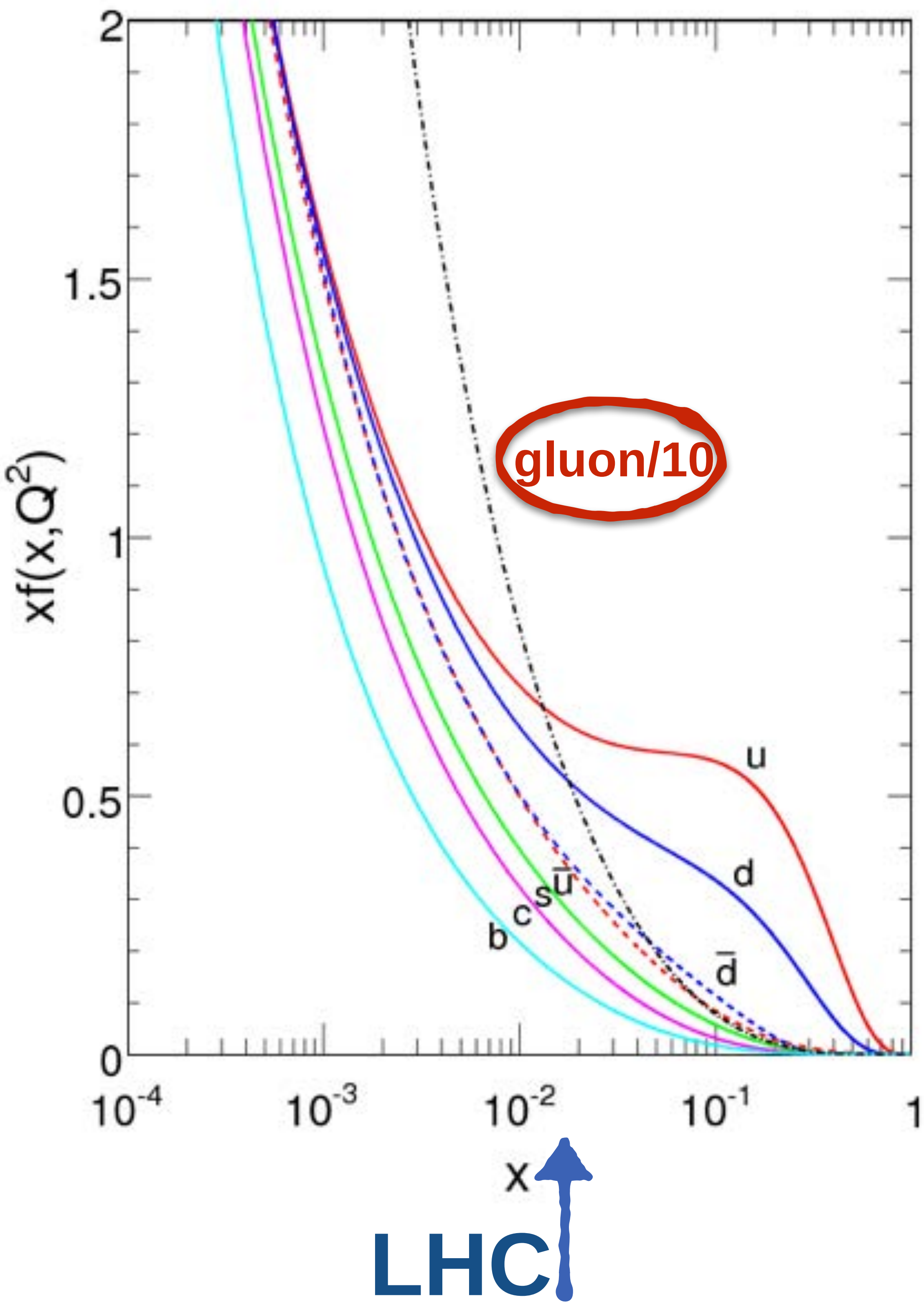
- Recently ATLAS & CMS published the Run-1 combined measurements of the Higgs production and decay rates and constraints on its couplings.
- This includes the combined value for the ttH signal strength:
  - $\mu_{ttH} = 2.3^{+0.7}_{-0.6}$
  - Significance: 4.4σ (2.0σ expected)
- Total combined signal strength:
  - $\mu = 1.09^{+0.11}_{-0.10}$

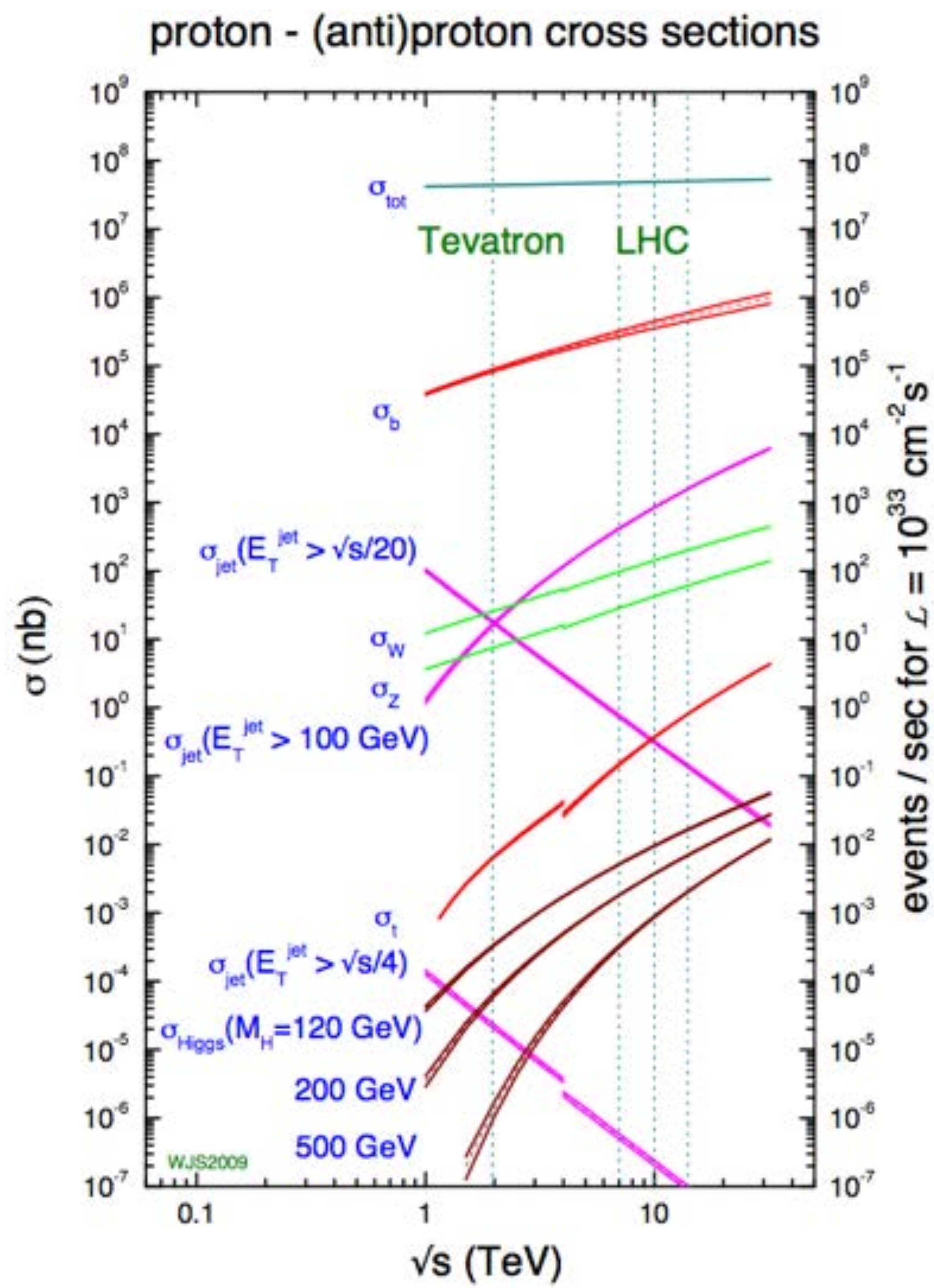




CMS ttH γγ leptonic √s = 8 TeV, L = 19.7 fb-1
Entries
Data sidebands
Control sample
mH=125.6GeV
Number of b-Jets
Number of Jets
CMS ttH γγ hadronic √s = 8 TeV, L = 19.7 fb-1

Differences between TeV and LHC





tHq to multilepton

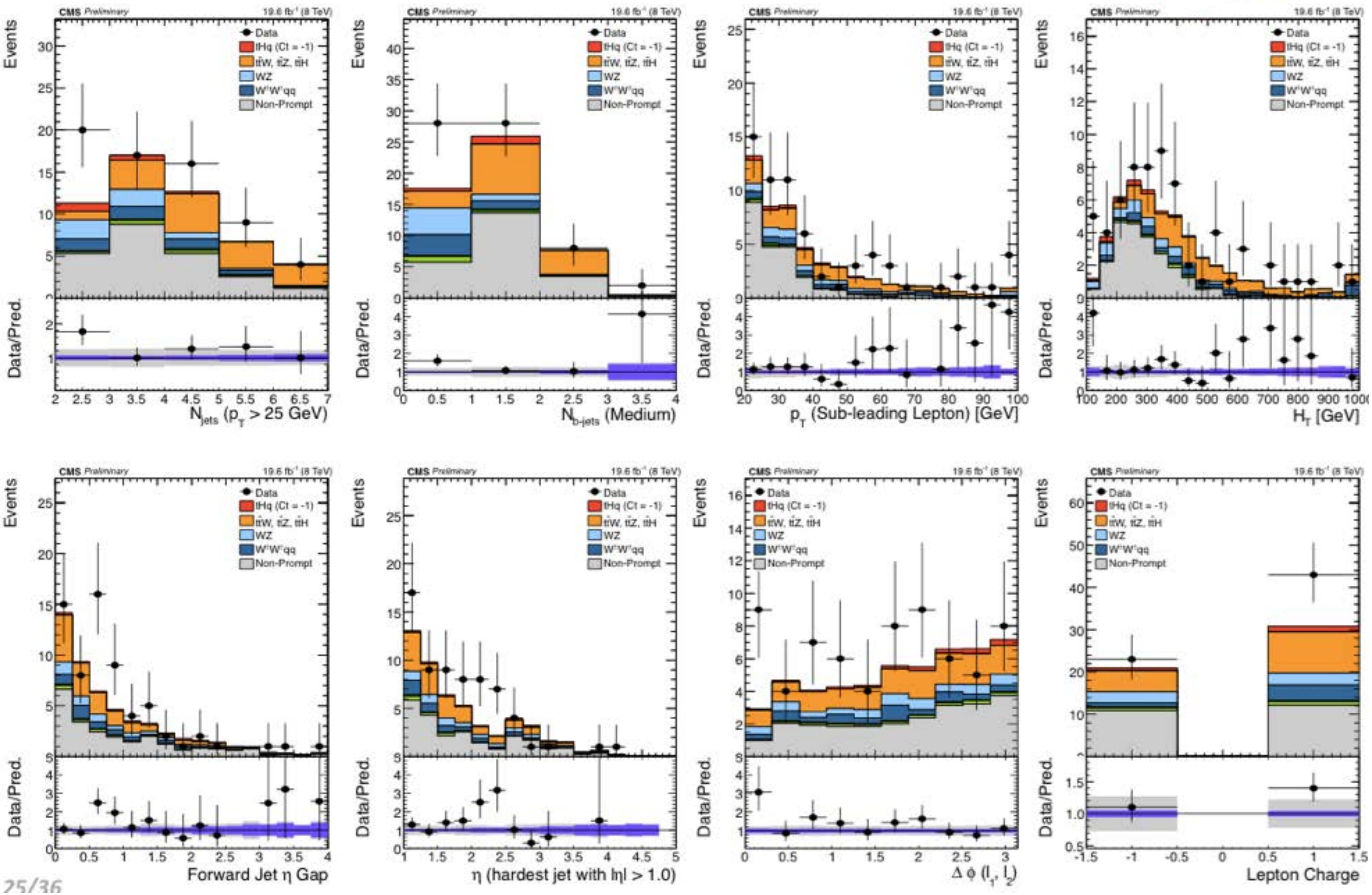
- **Same-sign di-leptons**, $p_T > 20/20$ GeV
  - No additional leptons (lep. mva > 0.35)
  - Minimum $m_{ll} > 12$ GeV
- One **central** jet **$|\eta| < 1.0$**, $p_T > 25$ GeV
- One **forward** jet **$|\eta| > 1.0$**, $p_T > 25$ GeV
- One CSV **loose b-tag**
- **No hadronic τ's**

- **Three leptons**, $p_T > 20/10/10$ GeV
  - No additional tight leptons
  - Minimum $m_{ll} > 20$ GeV
- One **forward** jet **$|\eta| > 1.5$**, $p_T > 25$ GeV
- One CSV **medium b-tag**
- **MET** > 30 GeV
- **Z veto**: $|m_{ll} - mZ| > 15$ GeV

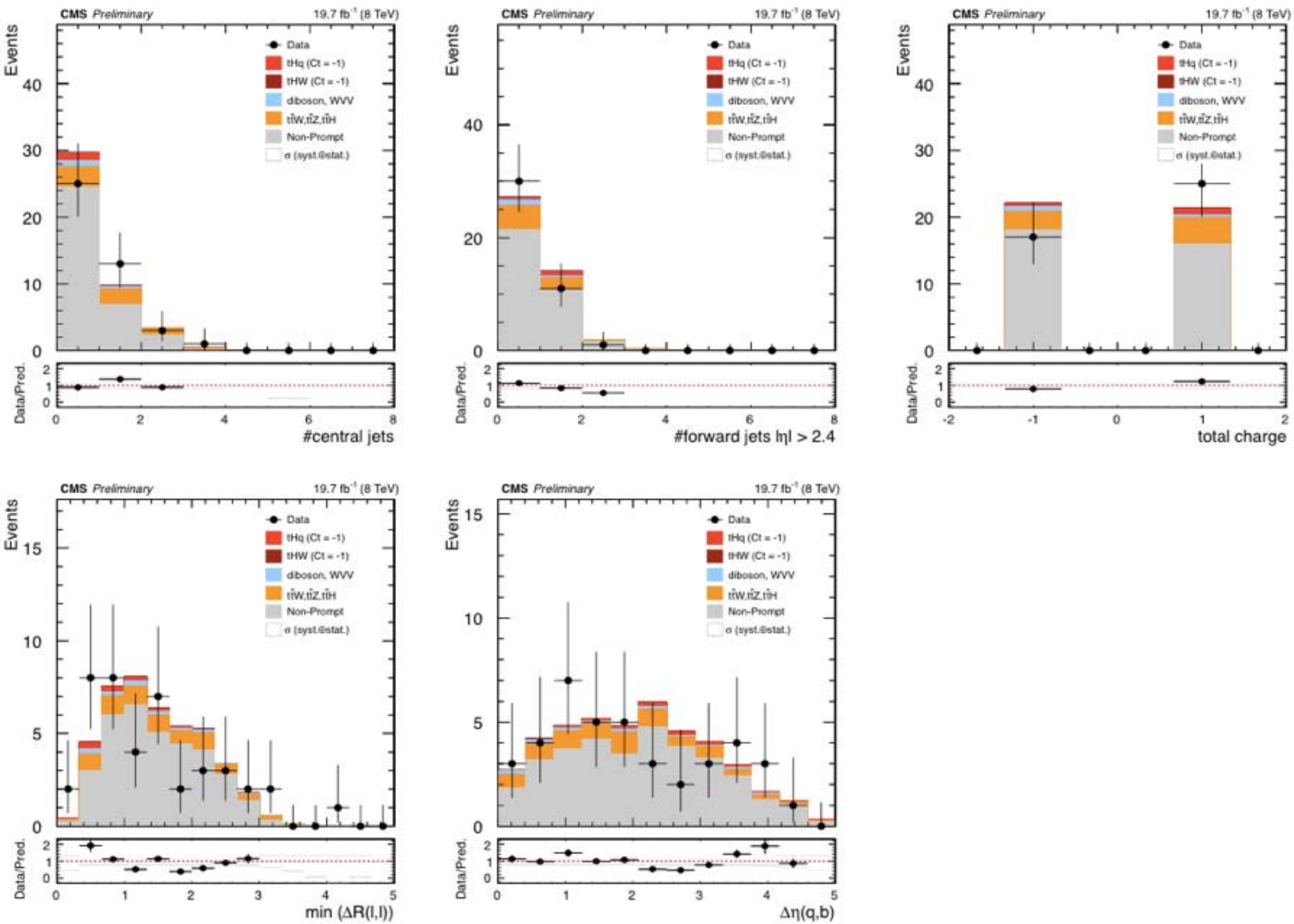
Note: Stat. errors only, Signal is $C_t = -1$

Process	$\mu\mu$	$e\mu$	$\ell\ell\ell$
W^+W^+qq	4.62 ± 0.48	6.05 ± 0.53	–
WZ, WW, ZZ	5.38 ± 0.24	8.71 ± 0.30	1.18 ± 0.06
Rare SM bkg.	1.41 ± 0.09	2.58 ± 0.12	0.11 ± 0.03
$t\bar{t}\gamma^*$	0.50 ± 0.05	1.04 ± 0.08	–
$t\bar{t}\gamma$	0.09 ± 0.05	2.02 ± 0.24	–
$t\bar{t}Z$	2.23 ± 0.21	2.87 ± 0.23	2.20 ± 0.18
$t\bar{t}W^\pm$	10.23 ± 0.50	14.95 ± 0.59	3.0 ± 0.3
$t\bar{t}H$	2.26 ± 0.08	3.24 ± 0.09	1.52 ± 0.06
Charge Mis-ID	–	6.99 ± 0.10	–
Non-Prompt	23.01 ± 1.46	50.96 ± 2.47	34 ± 6
Total Background	**49.73 ± 1.66**	**99.41 ± 2.64**	**41.9 ± 5.8**
$tH(\tau\tau)W$	0.06 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
$tH(WW)W$	0.16 ± 0.02	0.26 ± 0.02	0.19 ± 0.01
$tH(\tau\tau)q$	0.33 ± 0.02	0.50 ± 0.02	0.31 ± 0.01
$tH(WW)q$	1.41 ± 0.04	2.06 ± 0.04	0.95 ± 0.02
Total Signal	**1.95 ± 0.04**	**2.89 ± 0.05**	**1.51 ± 0.03**
Data	**66**	**117**	**42**

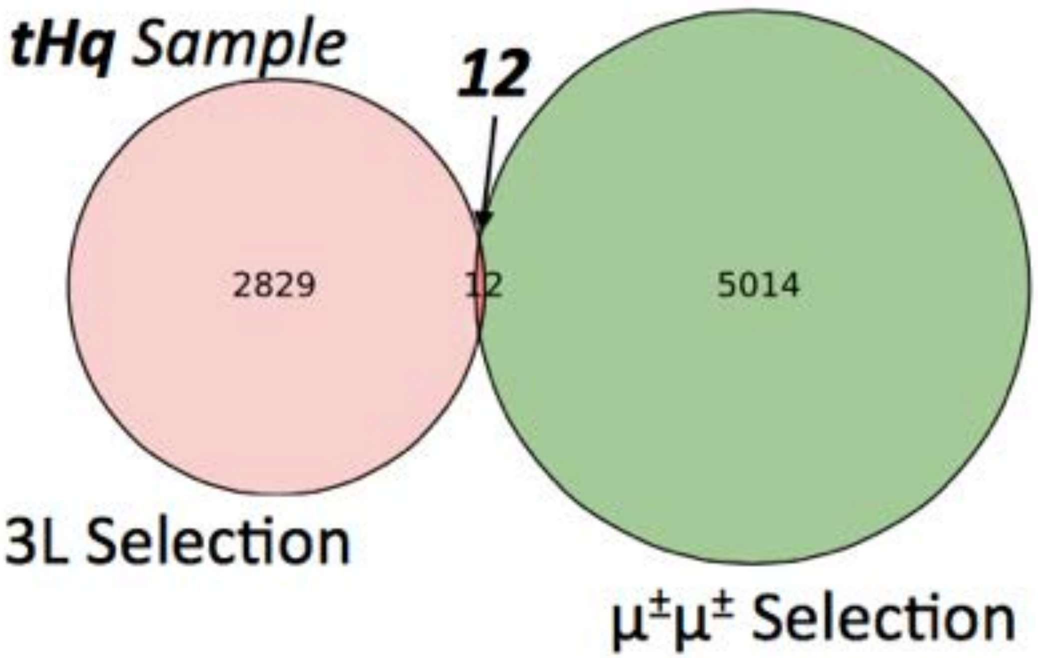
tHq to multilepton

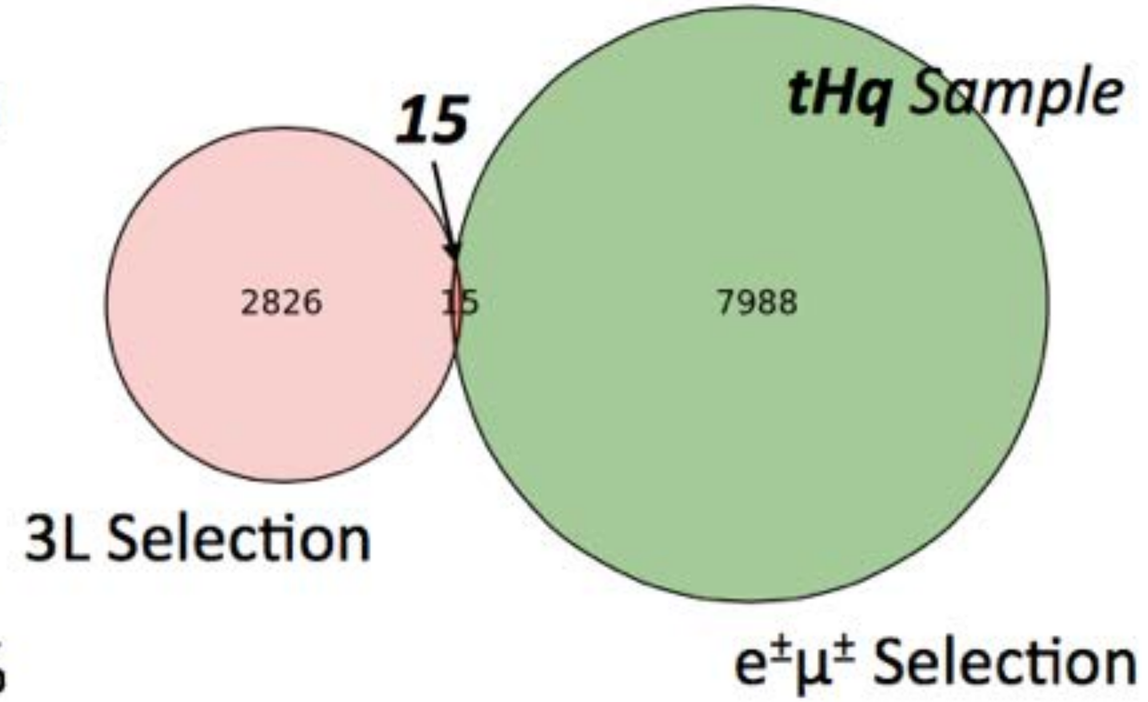


tHq to multilepton



Interchannel Overlap?





- Residual overlap well below 1%
- No common events on data

ttH and tHq multilepton

In the dilepton channels ($\mu\mu/e\mu$), ttH* has a tighter selection than tHq, but does not require forward jets

tHq 2lSS Selection

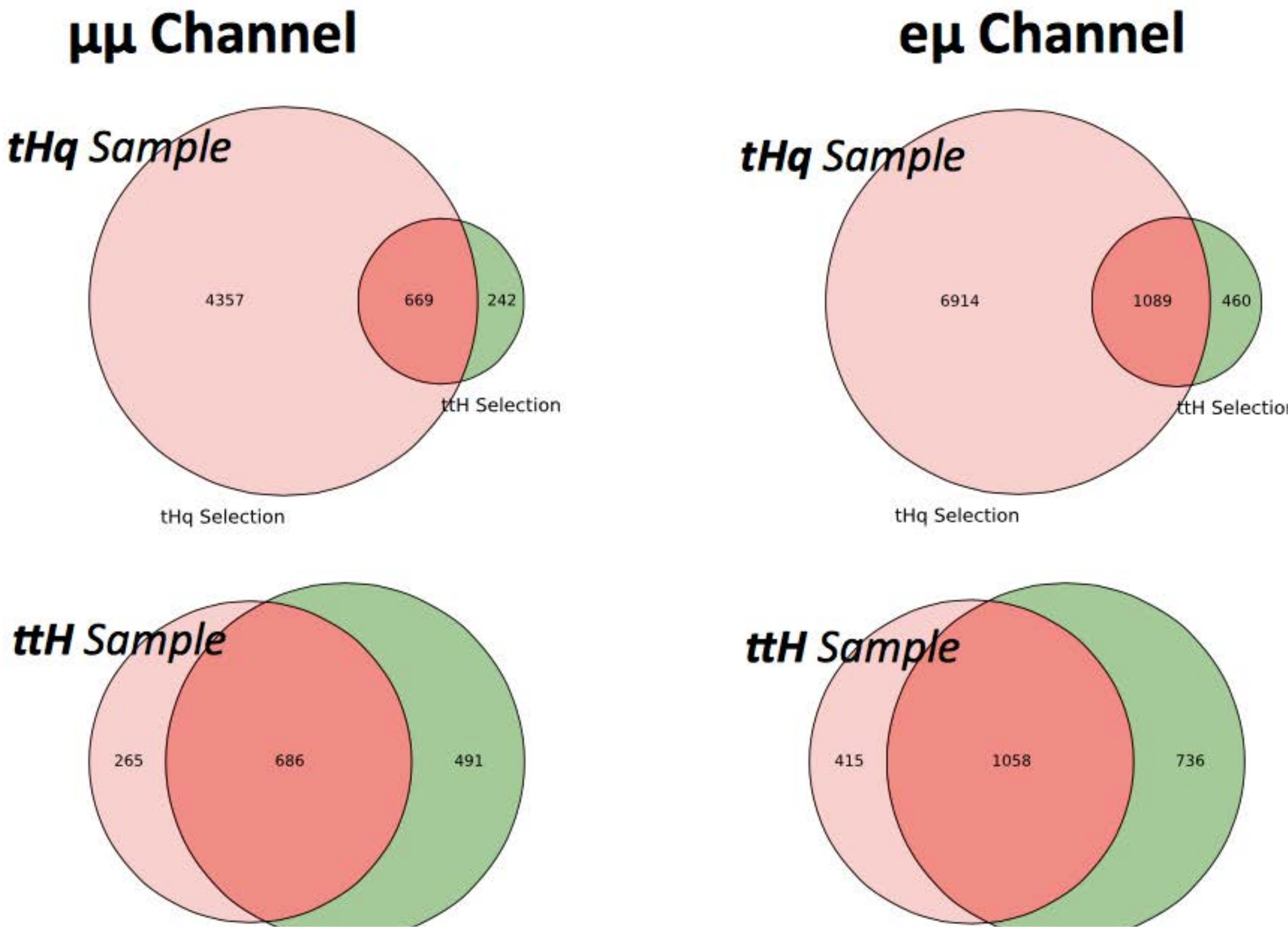
- **≥ 1 jet with |η| > 1**
- ≥ 1 jet with |η| < 1
- ≥ 1 jet with loose CSV tag
- Veto hadronic τ's

ttH 2lSS Selection

- $p_{T,1} + p_{T,2} + ME_T > 100$ GeV
- **≥ 4 jets (|η| < 2.4)**
- ≥ 2 jets with loose CSV **OR** ≥ 1 jet with medium CSV

- Remaining selection is identical
- By construction, no migration between tHq dilepton and ttH channels

Title



μμ Channel
eμ Channel
tHq Sample
4357
669
242
ttH Selection
tHq Selection
tHq Sample
6914
1089
460
ttH Selection
tHq Selection
ttH Sample
265
686
491
ttH Sample
415
1058
736

OVERLAP FOR 3L ANALYSIS

tHq 3l Selection

- ≥ 1 (non-tagged) fwd-jet ($|\eta| > 1.5$)
- $ME_T > 30$ GeV
- == 1 jet with med. CSV tag

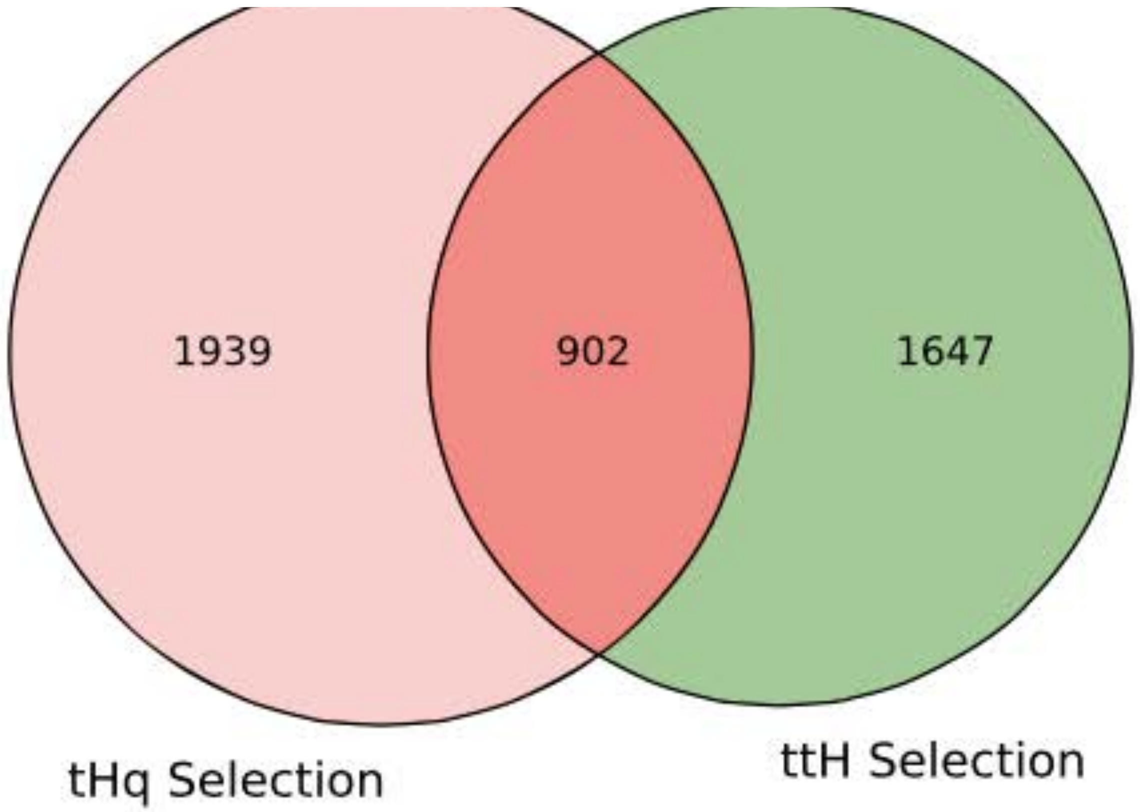
ttH 3l Selection

- ≥ 2 jets ($|\eta| < 2.4$)
- $ME_T LD^* > 0.2$ **OR** ≥ 4 jets
- ≥ 2 jets with loose CSV **OR** ≥ 1 jet with medium CSV

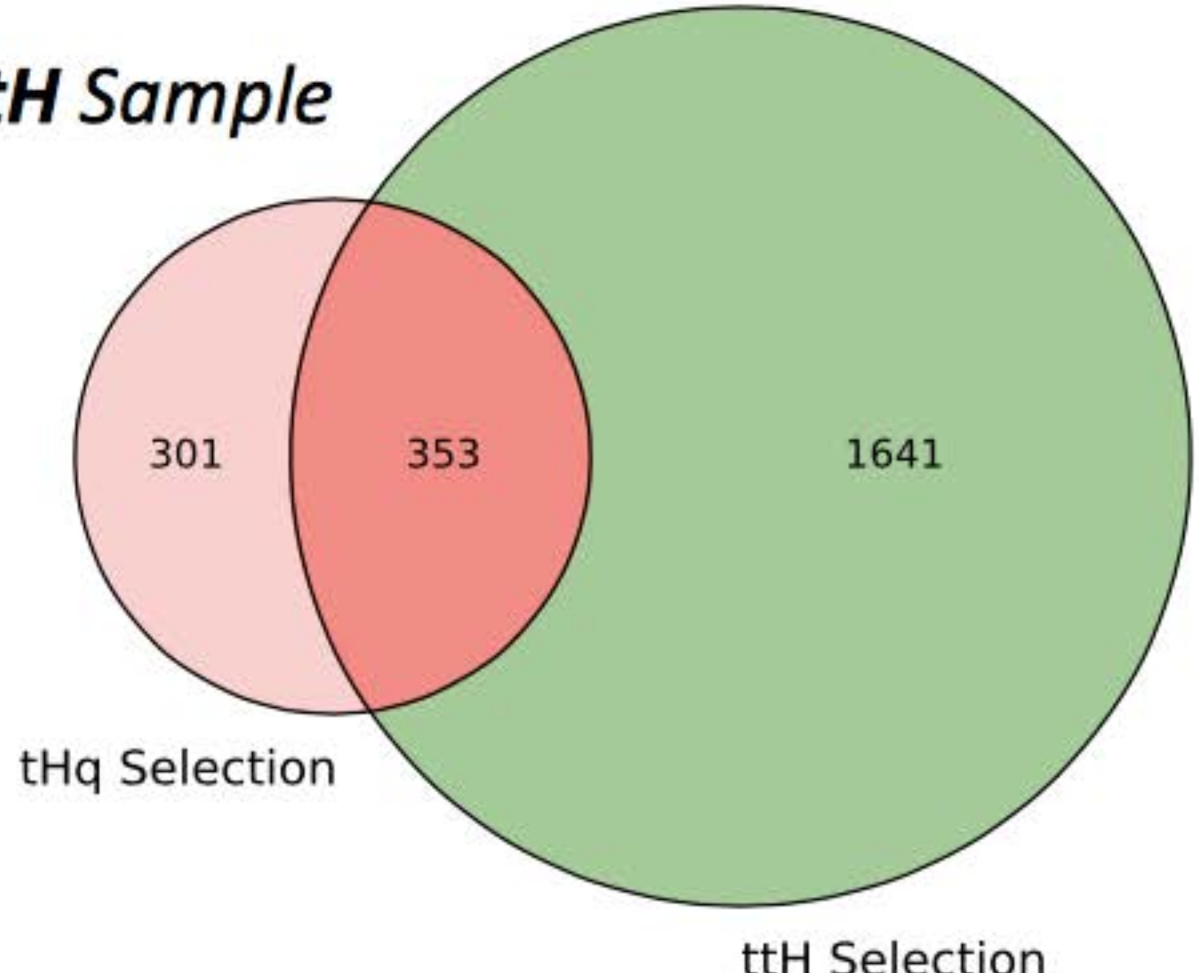
- Remaining selection very similar (Z-veto, m_{ll} cuts, add. lep veto)
- Different lepton object selections
- Possible migration between tHq-3l and ttH-2l channels (see sl. 50)

Title

3l Channel

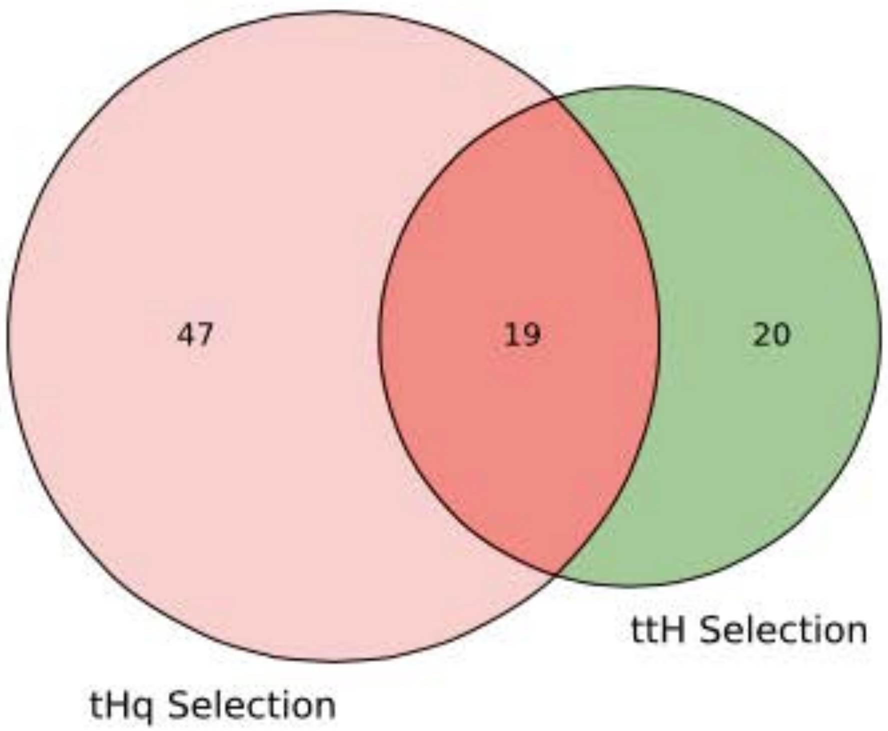


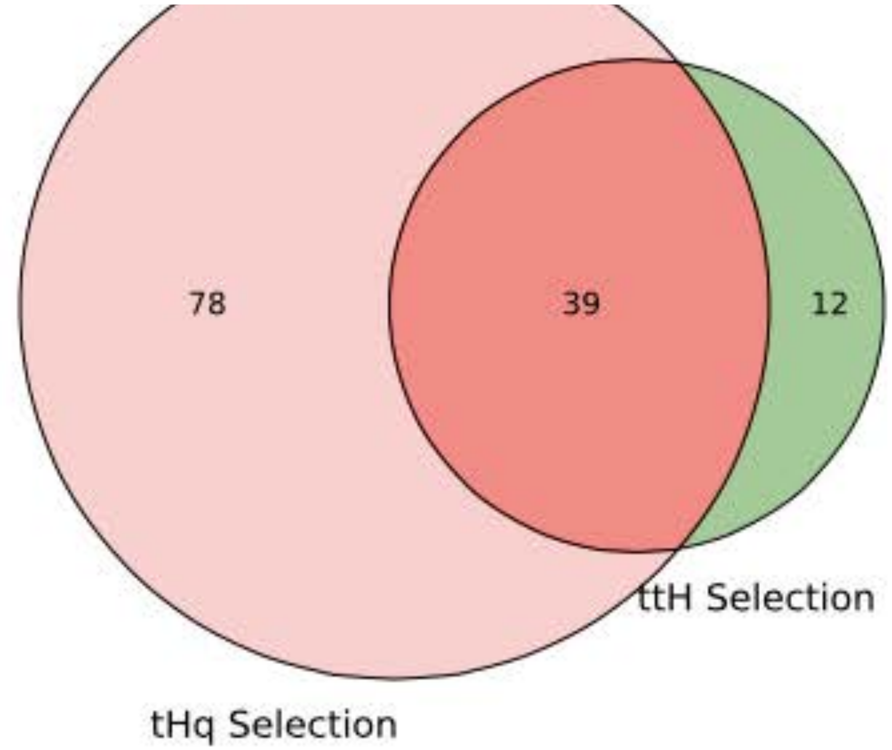
***ttH** Sample*



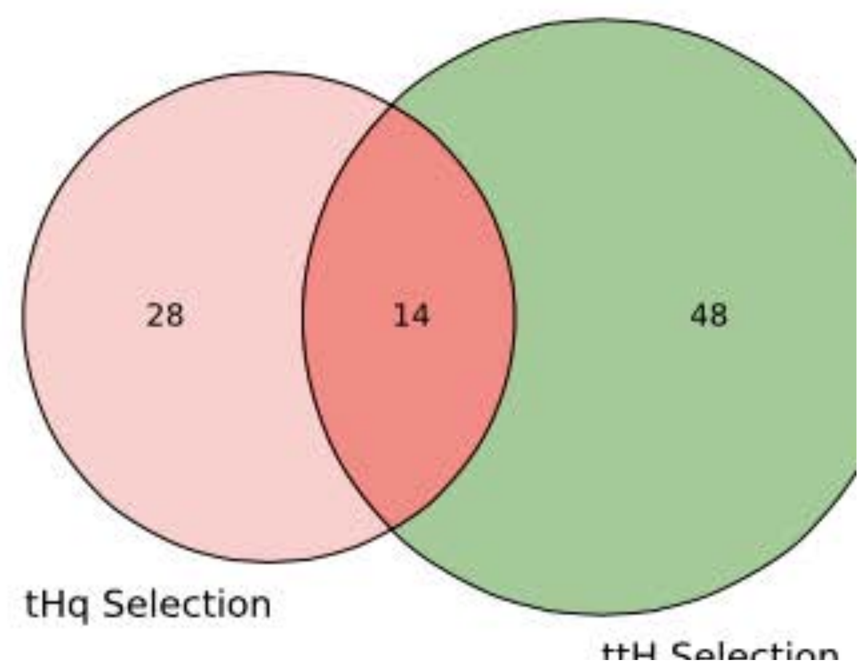
TITLE

μμ Channel



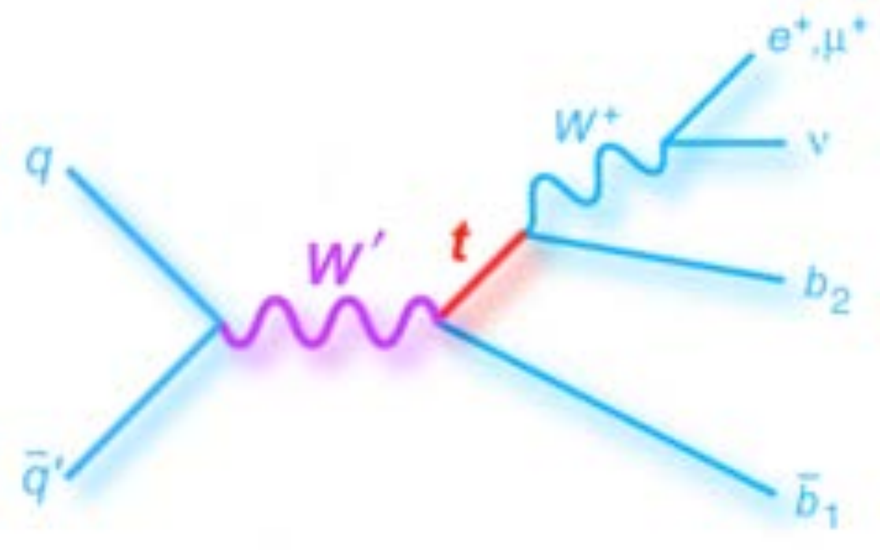


3l Channel

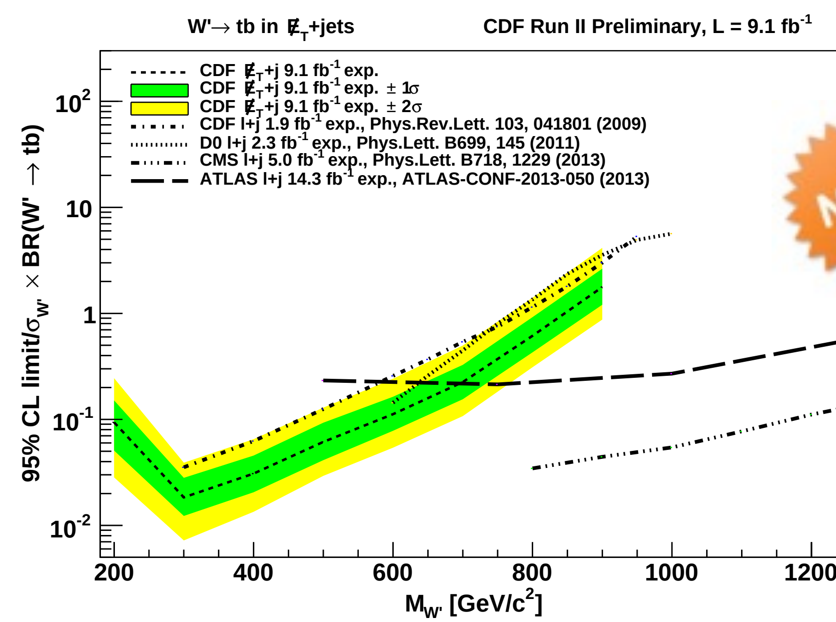


- Slight difference in yields of ttH selection compared to **HIG-13-020** PAS due to ReReco: 41 → 39 (μμ), 51 → 51 (eμ), 68 → 62 (3l)

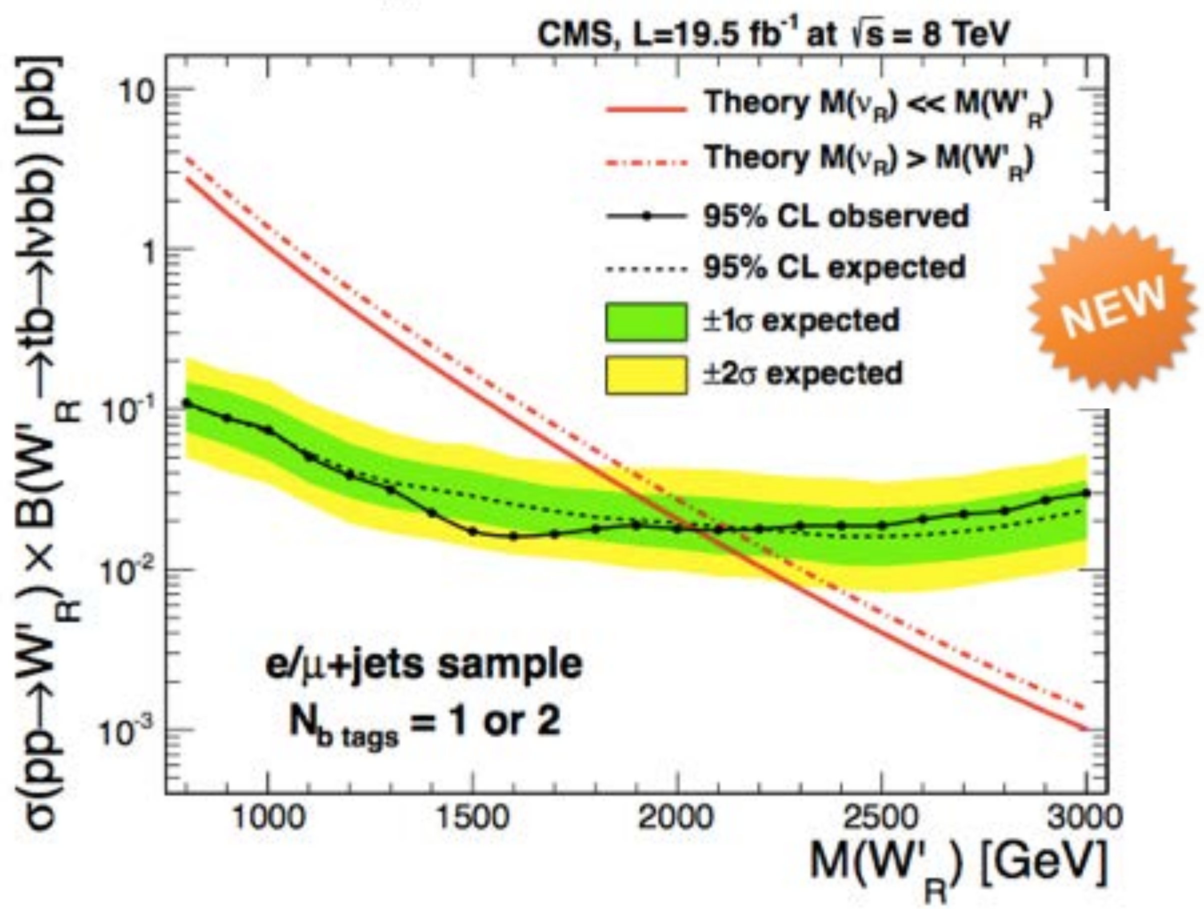
W'->TB



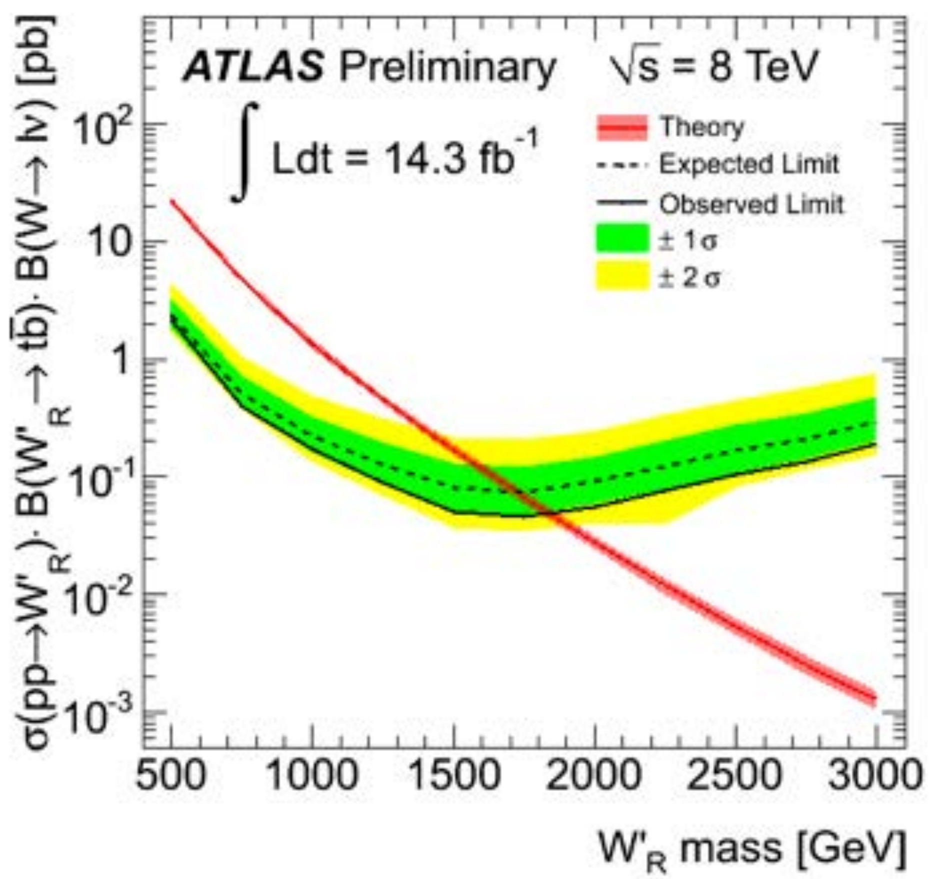
Conf. Note 11079



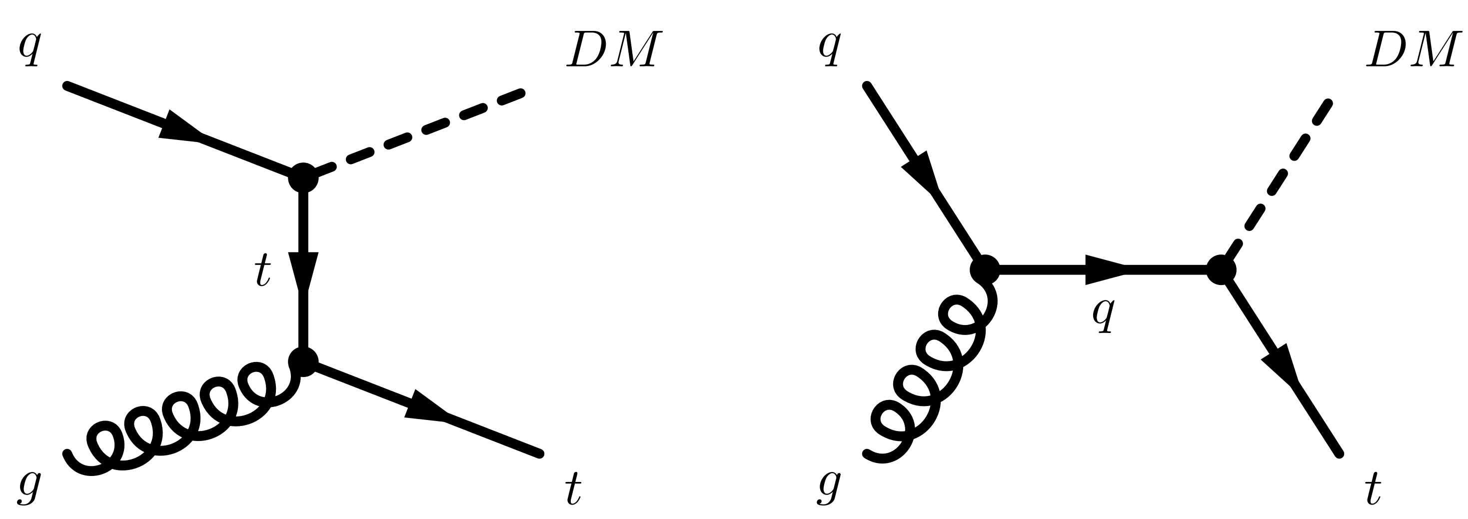
arxiv:1402.2176



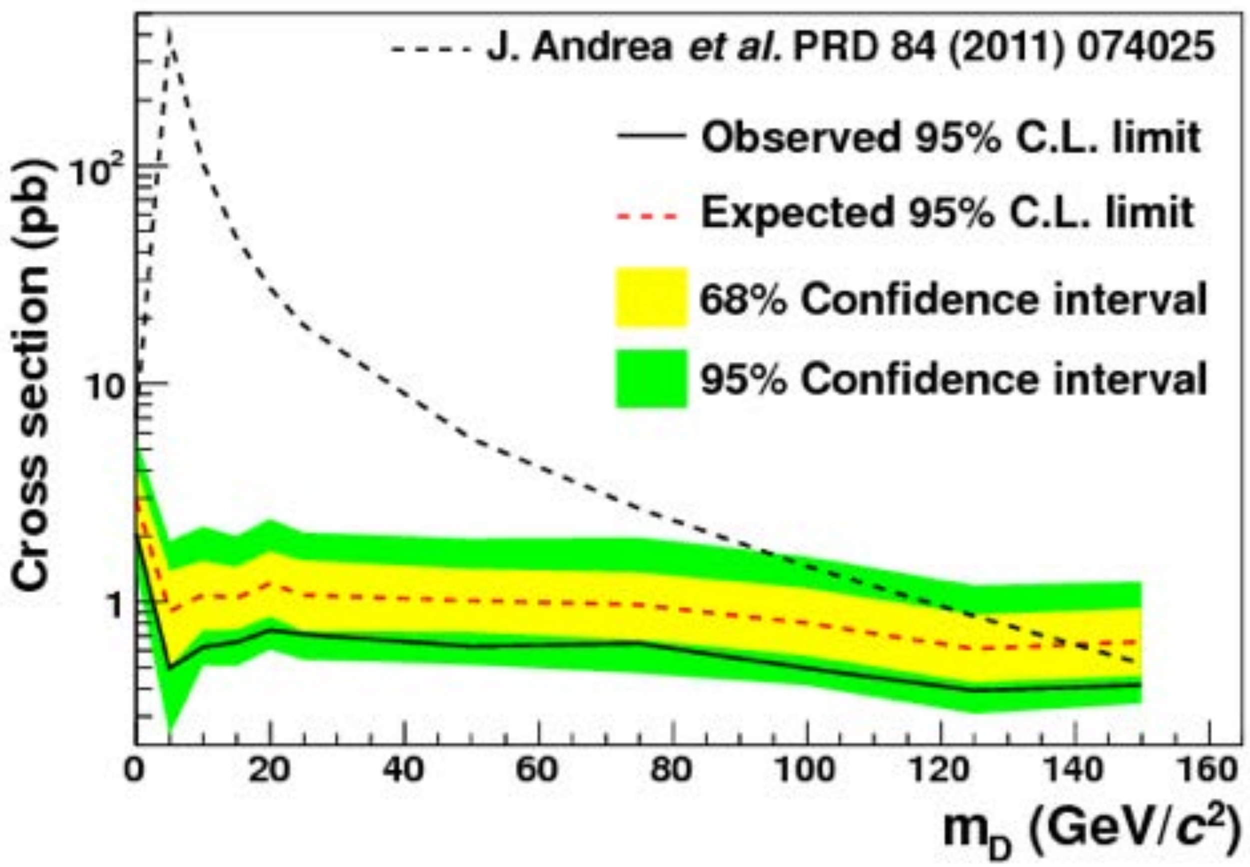
ATLAS-CONF-2013-050



MONOTOP



Phys.Rev.Lett. 108 (2012) 201802



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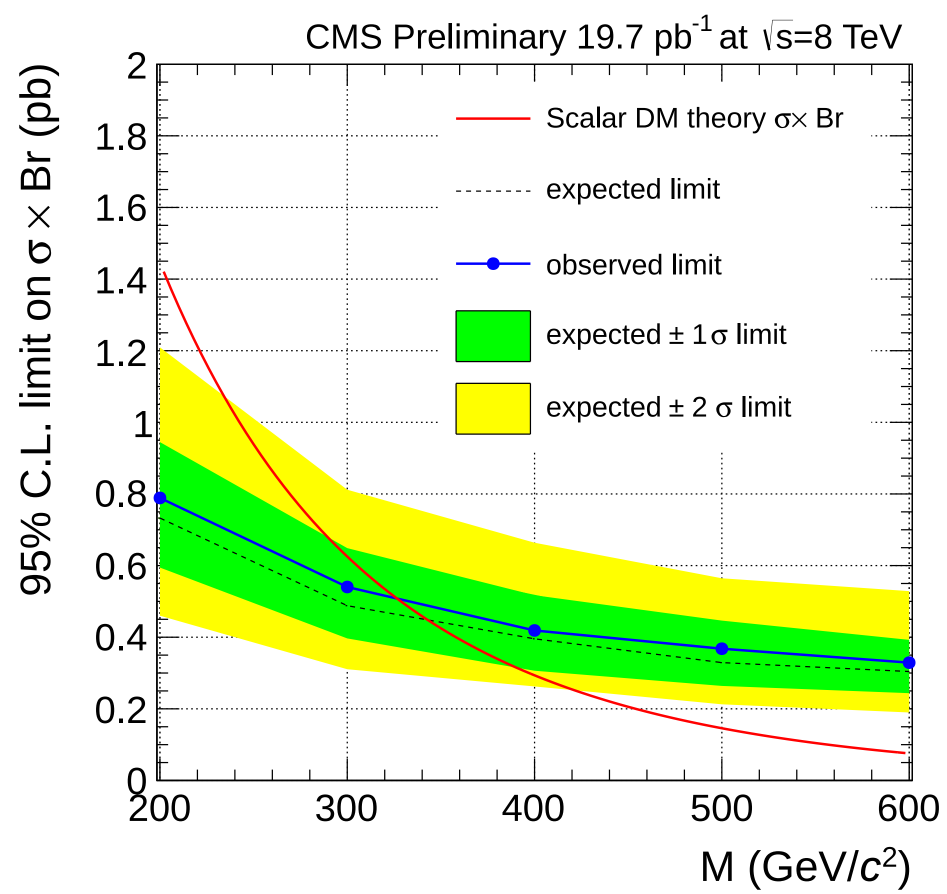
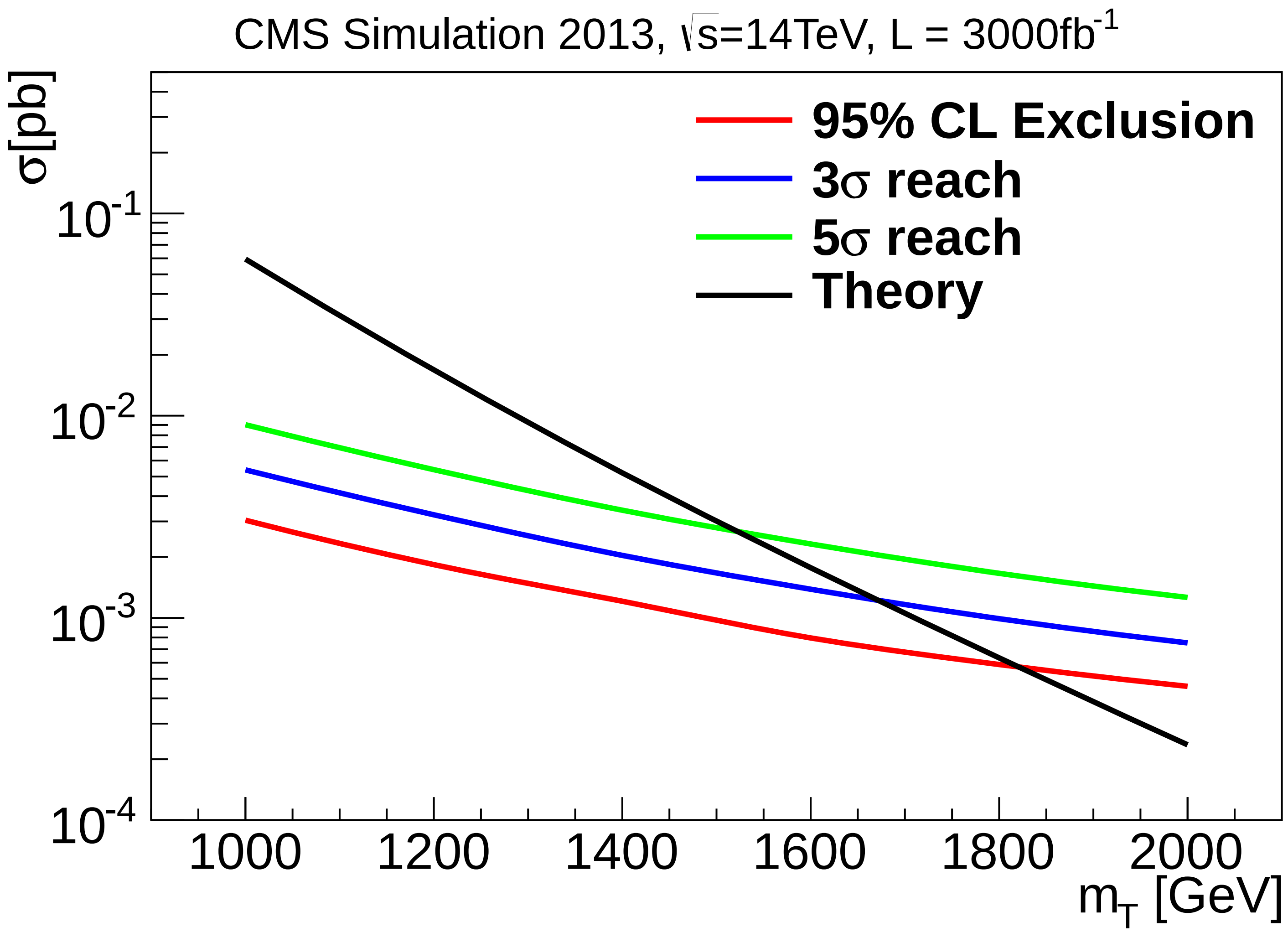
CMS-PAS-B2G-12-022



Fermionic top partners, projections to 3ab-1

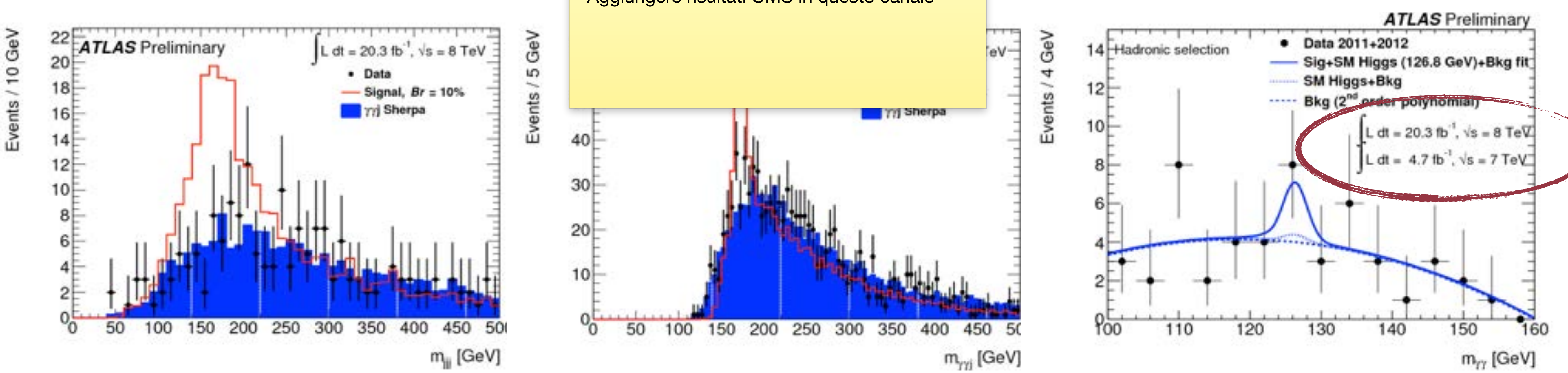


FCNC, Higgs boson

arXiv:1403.6293

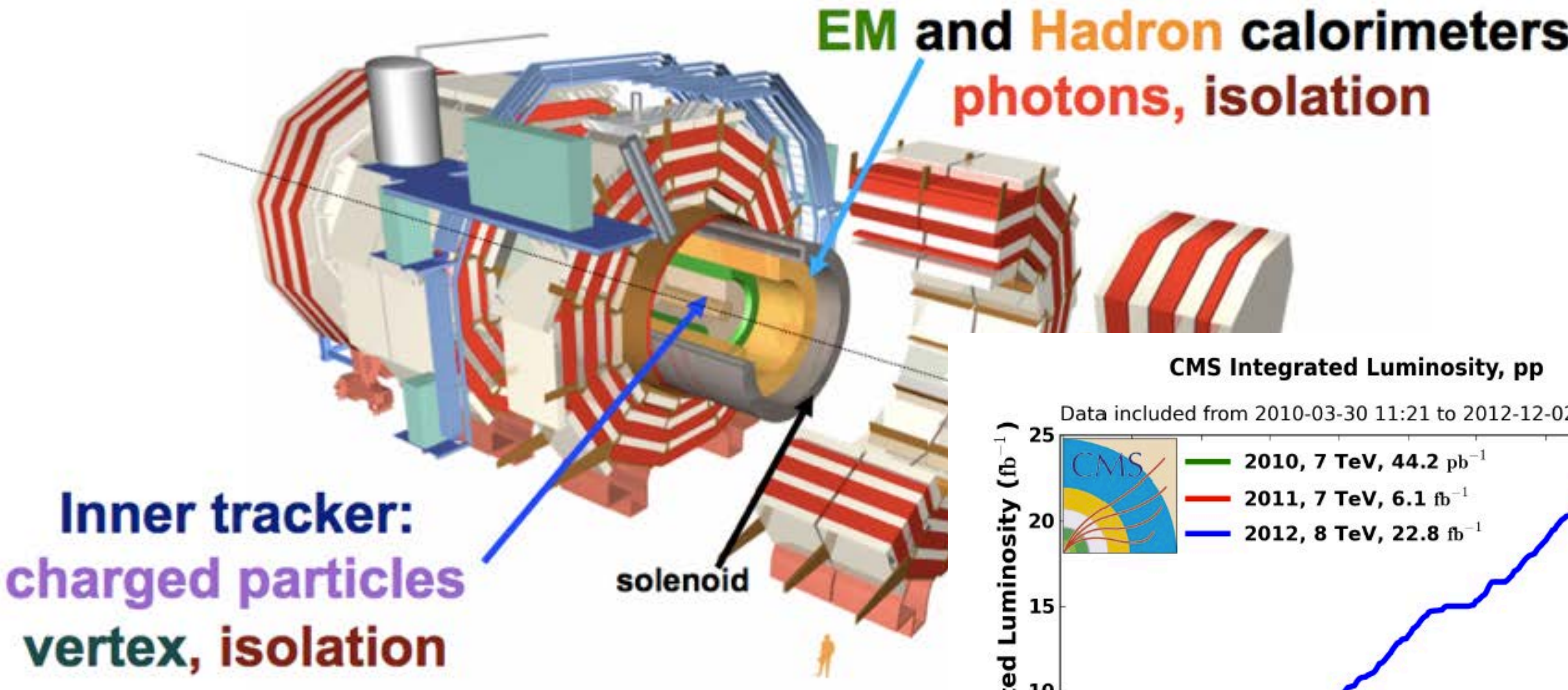
- Take the dominant ttbar production mode, look for events with one FCNC decay of the kind t→Hc
- Split into hadronic (tt→cHWb→cHqqb) events and leptonic (tt→cHWb→cgammagamma lnub) events
  - former contain residual combinatorics, latter unambiguous
- Choose topological and kinematic (top quark mass cuts) final states consistent with the FCNH hypothesis, scan over diphoton spectrum

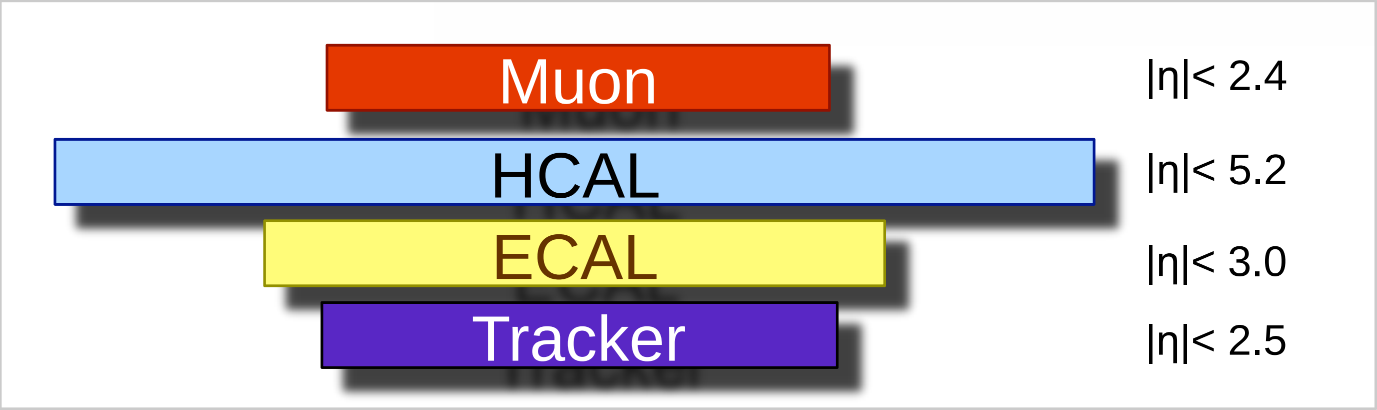
Aggiungere risultati CMS in questo canale

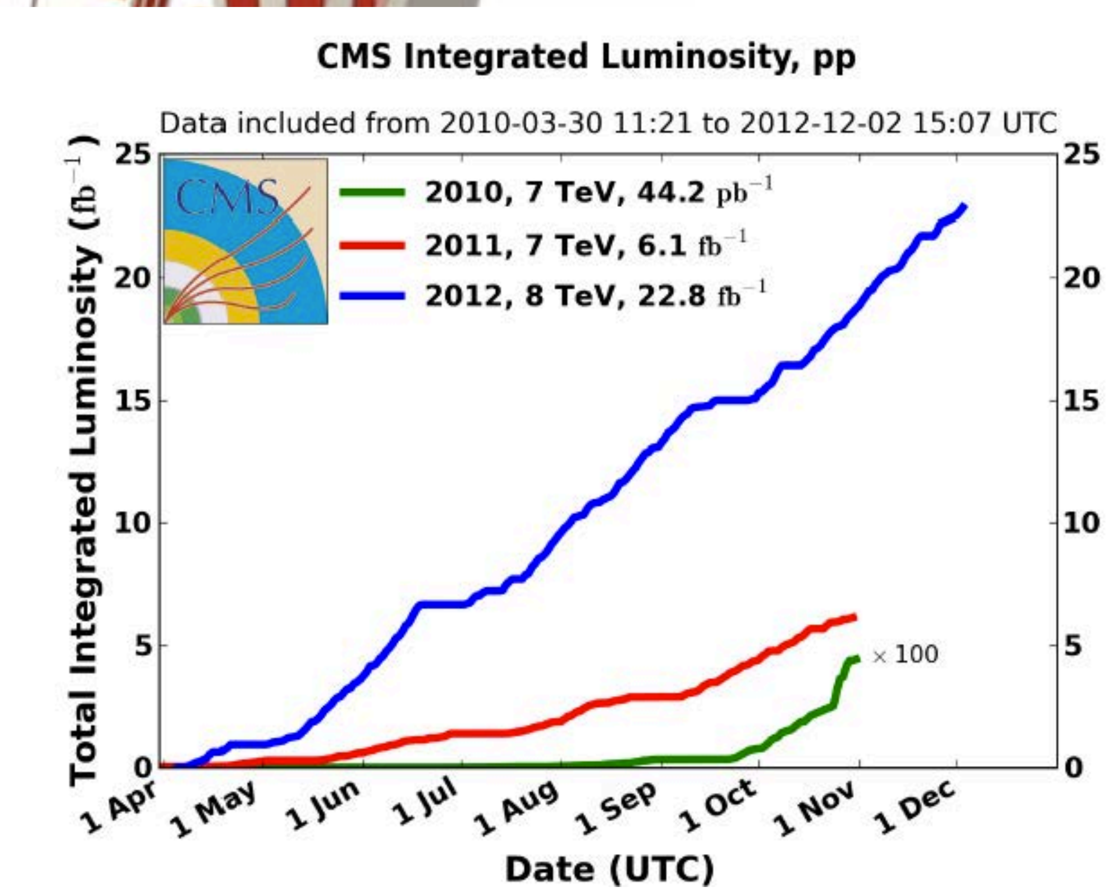


- No significant signal is observed and an upper limit on the branching ratio of 0.83% (0.53% expected) at the 95% confidence level is set. The corresponding limit on the tcH coupling is 0.17 (0.14 expected)

THE CMS DETECTOR







The search for ttH requires all subdetectors!

TECHNICALITIES

Signal and background modeling

- ttH, WW, WZ, ZZ Pythia
- ttW/ttZ/ttgamma/ttgammagamma/gamma+jets/gammagamma+jets MadGraph
- tq/tW Powheg

Triggers used:

- Diphoton trigger
- Electron trigger
- Muon trigger
- ee/emu/mumu triggers

btagging

- Combined secondary vertex, medium OP
- H->bb also uses full CSV spectrum

SYSTEMATICS THQ MULTILEPTON

- PDF and QCD scales (*rate*)
  - tHq: 4.6% from PDF, 1.1% from Q^2 scale
  - 10/11/6 % for ttW/ttZ/ttH from Q^2 scale
  - 7-9% for ttV from PDFs, 8% for ttH
- 4 vs 5 flavor scheme (*rate*)
  - Study difference in selection efficiency and cross section on parton level, assign 10% (SS2L), 16% (3L)
- Pileup reweighting (*rate*)
  - Vary total inelastic cross section by 5%

SYSTEMATICS THQ MULTILEPTON

- SS2L non-prompt estimate: **about 50%**
  - Data/MC agreement of fake rates: 50% (μμ), 40 % ⊕ 20 % (eμ) (rate)
  - Variations of fake rate by p_T/η (10-20%) (shape)

- SS2L charge mis-identification estimate: **about 30%**
  - Propagated uncertainty on measured probabilities (rate)

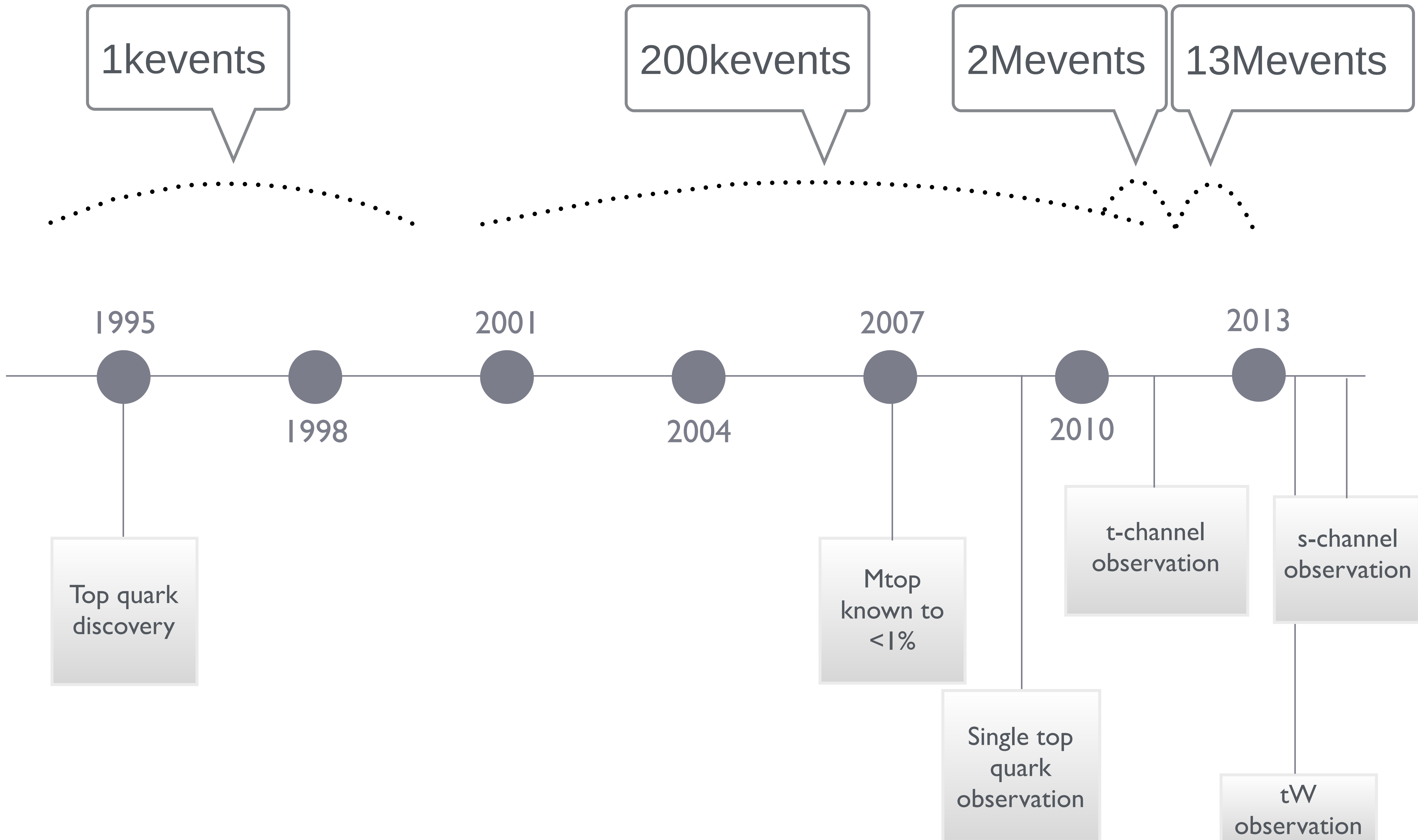
- 3L non-prompt estimate: **about 35%**
  - MC closure test (30%) (rate)
  - Statistical errors of measured fake rates (shape)
  - Varying the ME_T cut in control region (shape)

LEPTON MVA

Next, a multivariate discriminator based on BDT techniques is used to distinguish prompt from non- prompt leptons. This discriminator, referred to as the lepton MVA, is trained with simulated prompt leptons from the ttH MC sample and non-prompt leptons from the tt+jets MC sample, separately for electrons and muons and for several bins in pT and η.

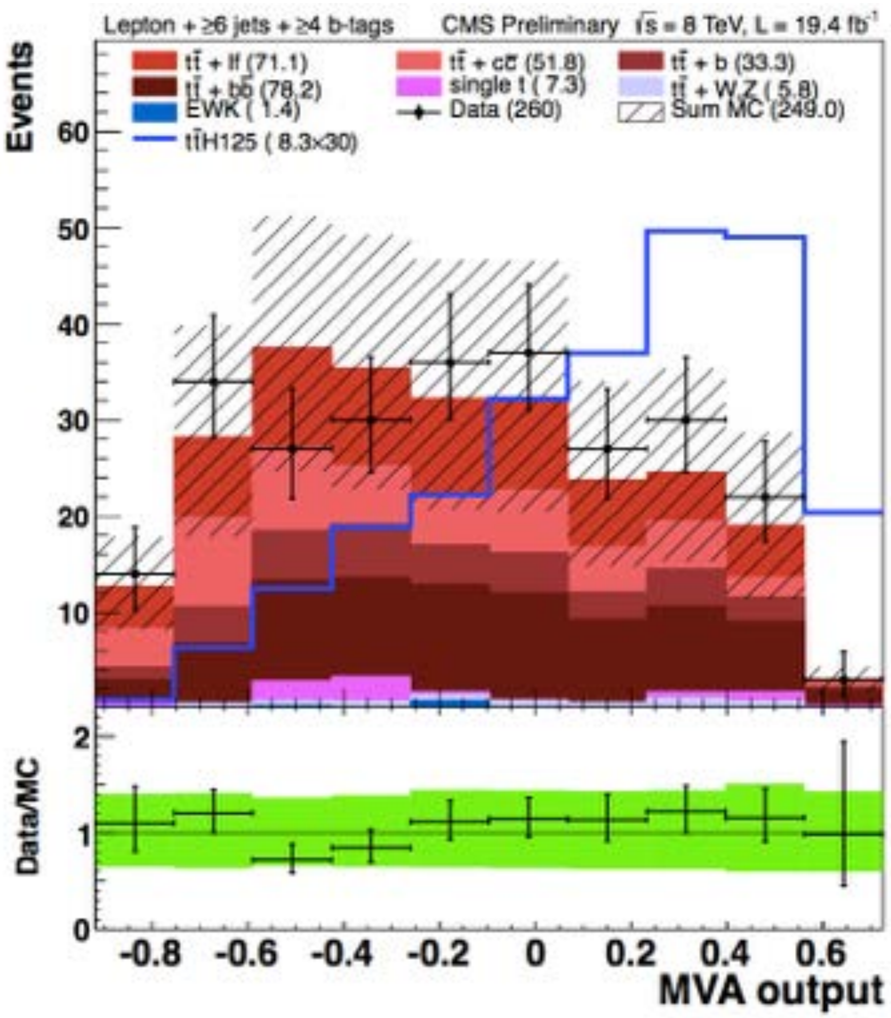
The lepton MVA input variables relate to the lepton IP, isolation, and the properties of the nearest jet, within $\Delta R < 0.5$. A tight working point on the lepton MVA output is used for the search in the dilepton and trilepton final states, and a loose working point is used for the four-lepton final state. For the tight working point, the efficiency to select prompt electrons is of order 35% for peT ~ 10 GeV and reaches a plateau of 85% at peT ~ 45 GeV; for prompt muons it is of order 55% for pTμ ~ 10 GeV, and reaches a plateau of about 97% at pTμ ~ 45 GeV. The efficiency to select electrons (muons) from the decay of b hadrons is between 5–10% (around 5%).

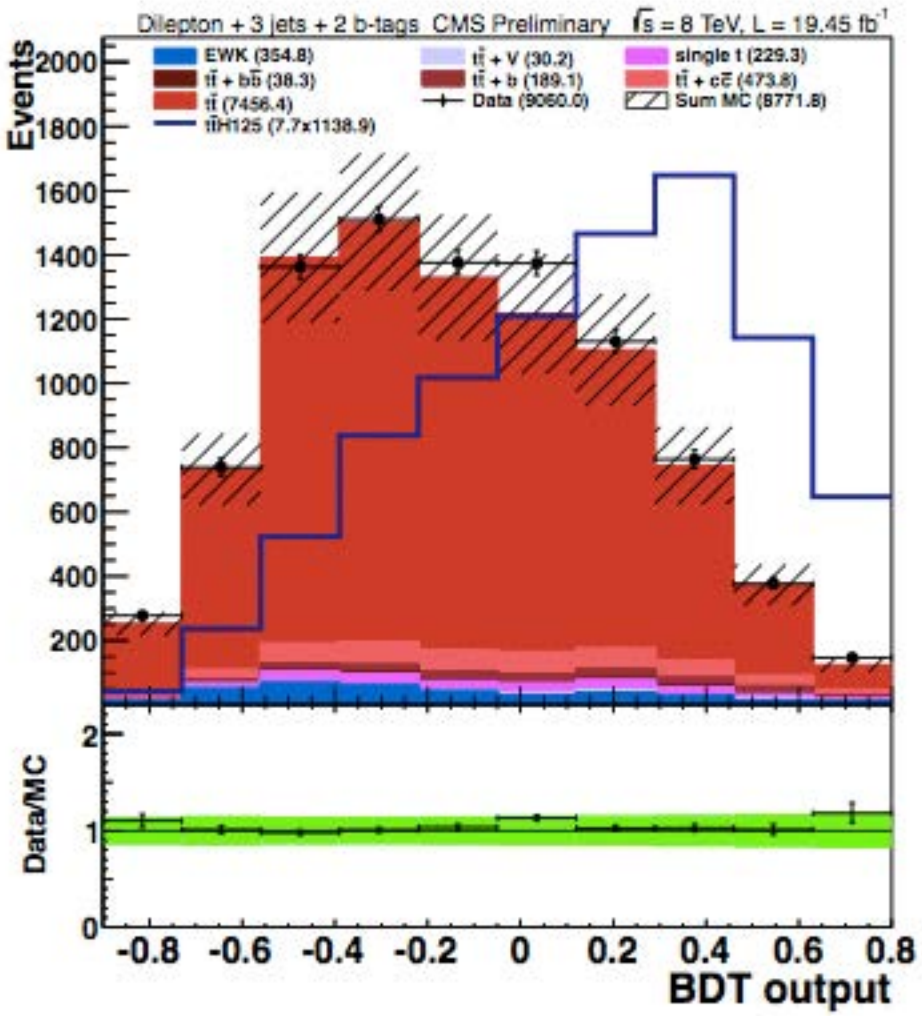
LIFE OF A QUARK



H → BB, TT → LJETS OR DILEPTON

- Identify tops and Higgs via multiple b-tagged jets, leptons (ele/muons) and light flavor jets
- Split into Njet/Nbtag categories to further increase sensitivity
- For each category, use machine learning techniques to discriminate signal from dominant tt +bb/cc/b backgrounds

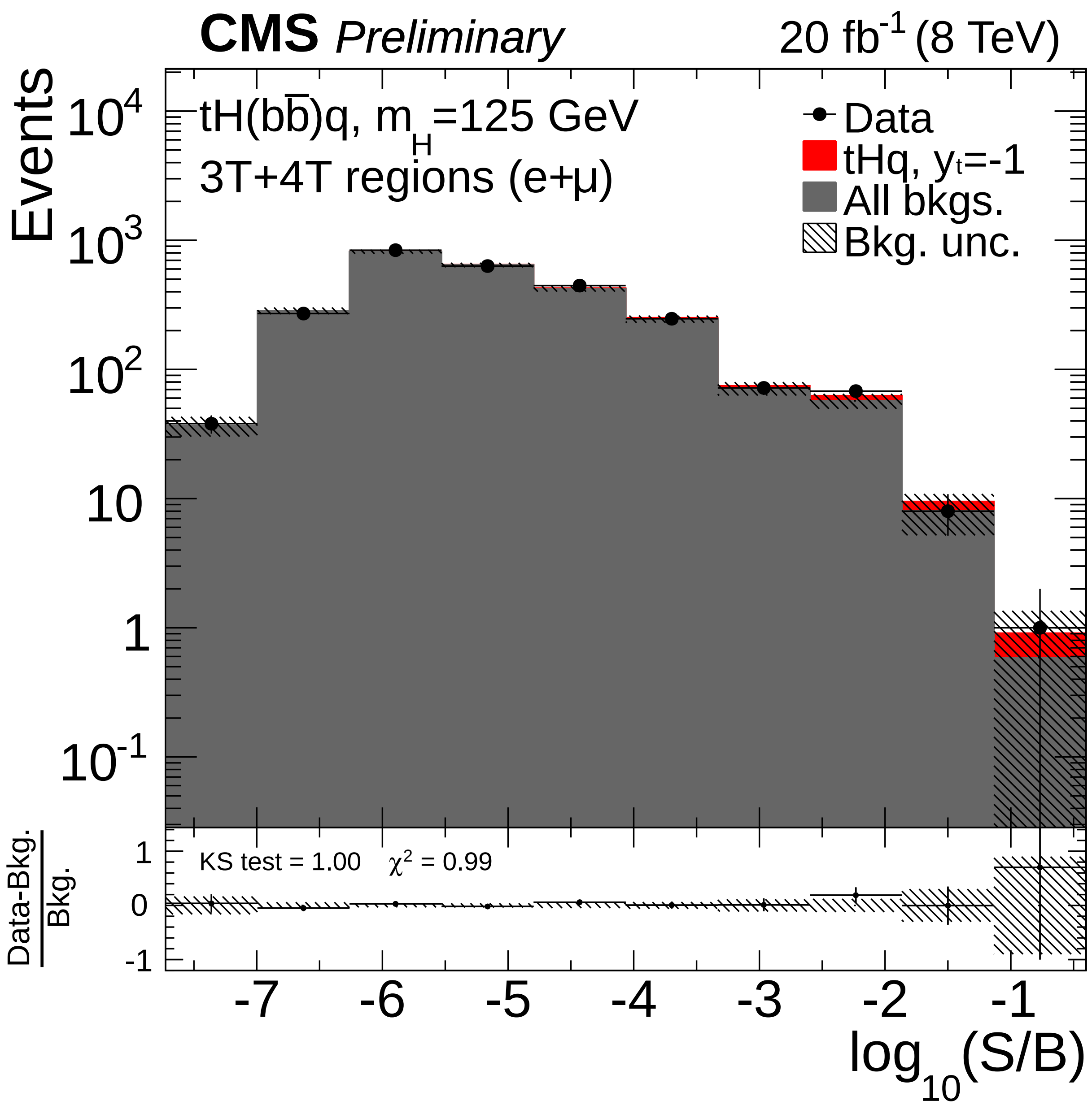




- Fit over resulting shapes, systematics modify relative normalization and shapes themselves
  - largest systematic is on the poorly known tt+bb/cc/b background

tHq, Higgs to bottoms

CMS-HIG-14-001



Process	Muon channel	Electron channel
$t\bar{t}$	1058 ± 5	718 ± 4
Single top	39 ± 3	27 ± 3
Electroweak	17^{+7}_{-5}	11 ± 7
$t\bar{t}H$	12.87 ± 0.17	9.35 ± 0.15
Total background	1128 ± 9	767 ± 10
tHq, $y_t = -1$	7.54 ± 0.03	5.15 ± 0.02
S/B ratio	0.7%	0.7%

Process	Muon channel	Electron channel
$t\bar{t}$	29.1 ± 0.8	19.8 ± 0.7
Single top	$1.1^{+0.8}_{-0.6}$	1.2 ± 1.0
Electroweak	4^{+6}_{-4}	5^{+6}_{-4}
$t\bar{t}H$	1.72 ± 0.06	1.43 ± 0.05
Total background	37^{+6}_{-4}	29^{+7}_{-4}
tHq, $y_t = -1$	0.835 ± 0.010	0.580 ± 0.009
S/B ratio	2.3%	2.0%

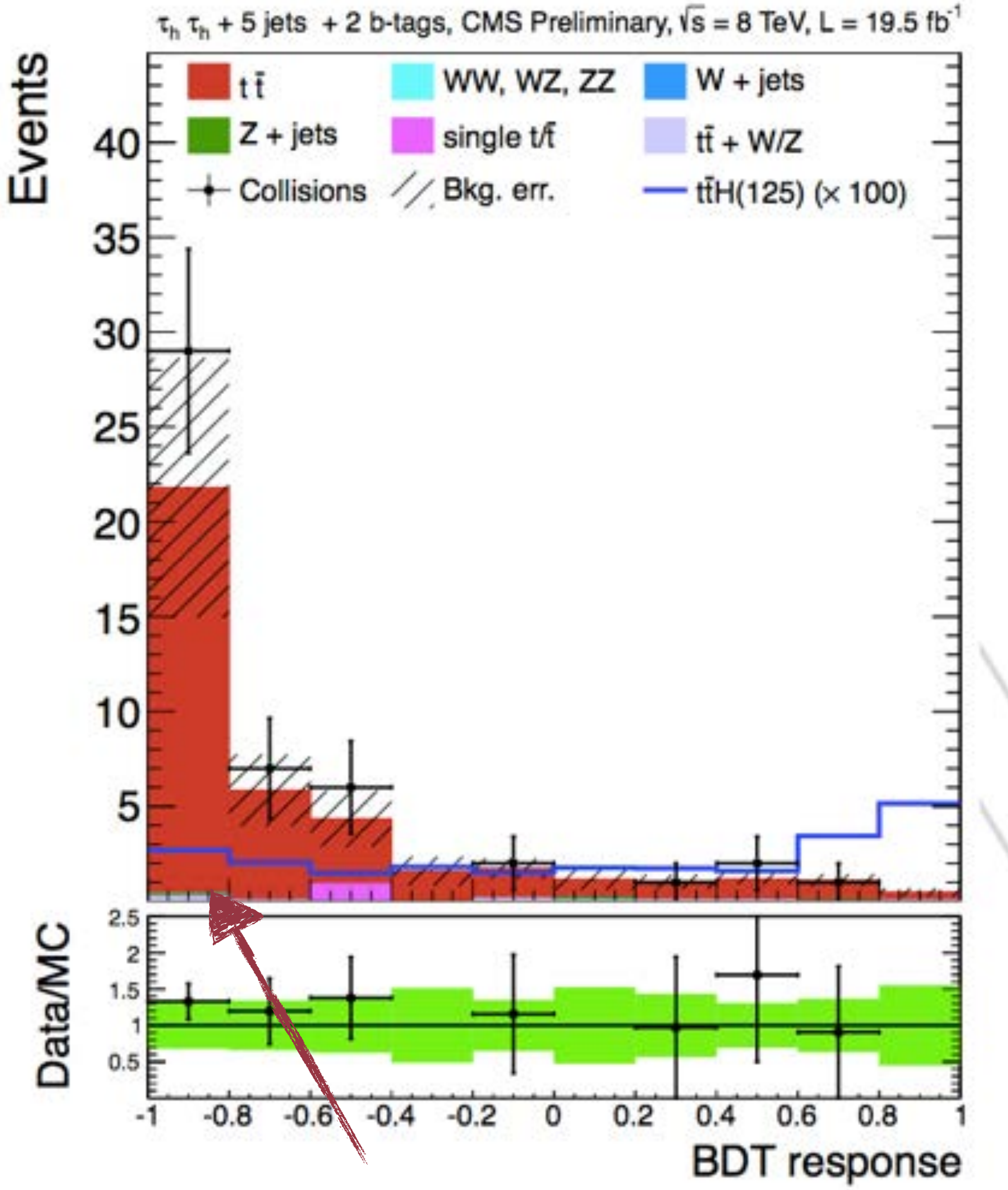
- Set 95% expected (observed) upper level confidence limit of 5.1 (7.6) the sigmaXBR for tHq production with negative Yukawa

TTH, H → TAUTAU

- Select hadronically decaying taus, coming from the Higgs decay, reconstructed via a Particle Flow algorithm
- Select additional b-jets, leptons, light flavor jets consistent with ttbar decays, split into Njets and Nbtags categories

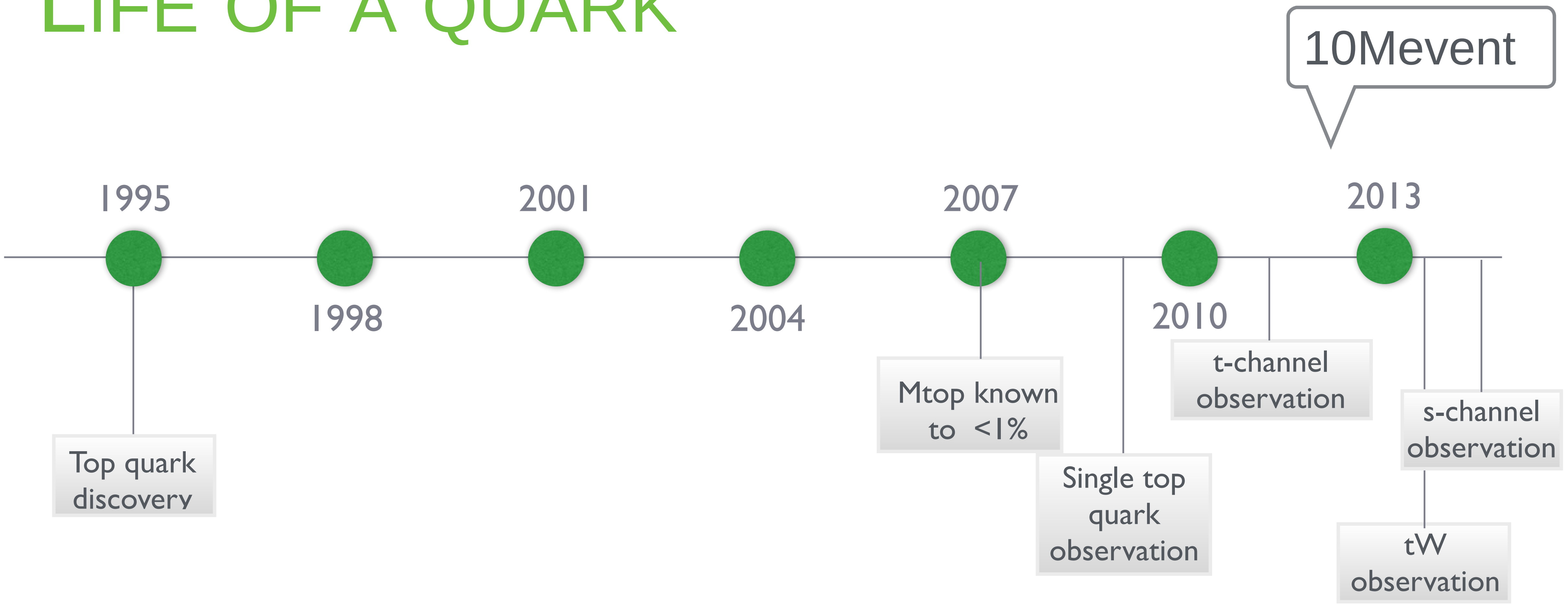
	4 jets 1 b-tag	5 jets 1 b-tag	≥6 jets 1 b-tag	4 jets 2 b-tags	5 jets 2 b-tags	≥6 jets 2 b-tags
$t\bar{t}H(125)$	0.4 ± 0.1	0.6 ± 0.1	0.6 ± 0.2	0.1 ± 0.0	0.2 ± 0.1	0.4 ± 0.1
$t\bar{t}$	225 ± 69	119 ± 38	64 ± 22	48 ± 15	38 ± 12	27.0 ± 9.1
$t\bar{t}V$	1.1 ± 0.3	1.3 ± 0.3	1.4 ± 0.4	0.4 ± 0.1	0.6 ± 0.2	1.1 ± 0.3
Single t	11.2 ± 4.0	3.0 ± 1.4	1.1 ± 1.0	1.9 ± 1.1	0.9 ± 0.6	0.6 ± 0.7
V+jets	33 ± 17	11.7 ± 6.8	3.8 ± 2.8	1.4 ± 0.9	0.4 ± 0.3	0.5 ± 0.6
Diboson	0.9 ± 0.2	0.7 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1
Total bkg	271 ± 82	135 ± 41	71 ± 24	52 ± 16	40 ± 12	29.2 ± 9.4
Data	292	171	92	41	48	35

- Here tt+jets is again dominant background
  - multivariate discriminants exploit mostly tau-related informations
- Total Ns~2.5 evts
  - x10 (H → bb, ttbar → dilepton)
  - x100 (H → bb, ttbar → l+jets)

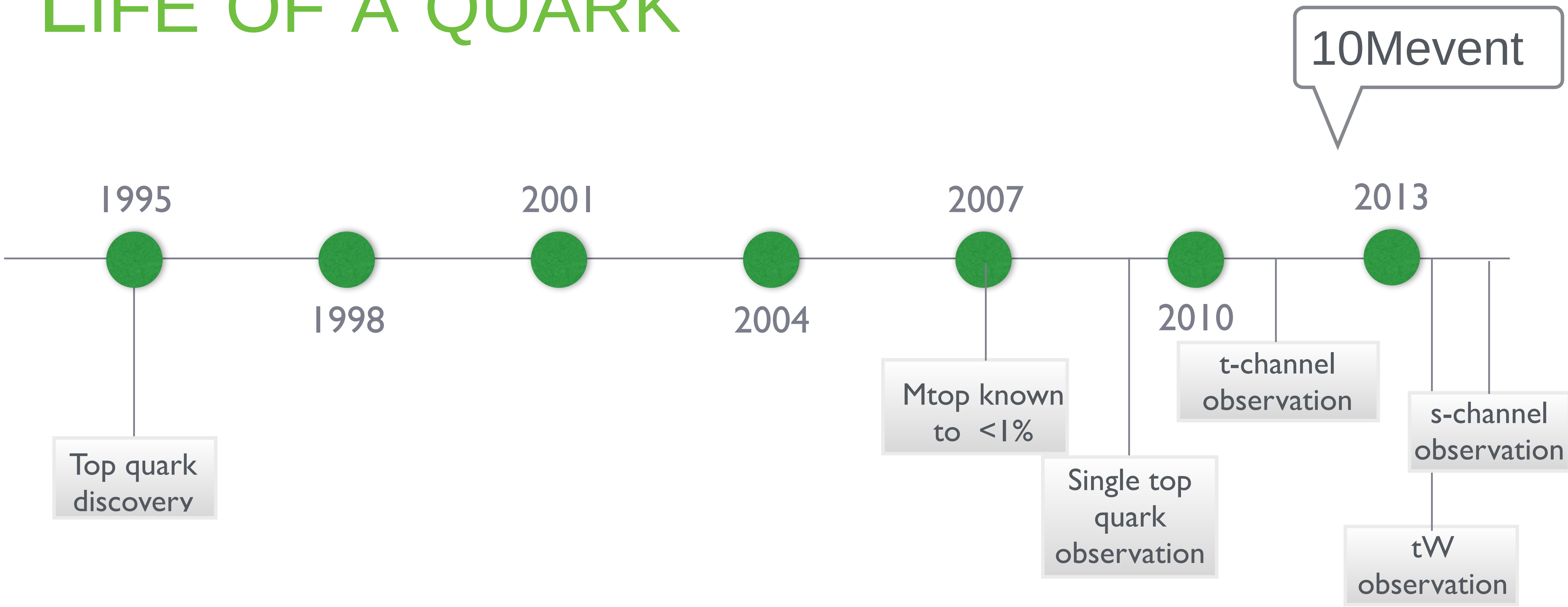


Non H→tautau ttH component

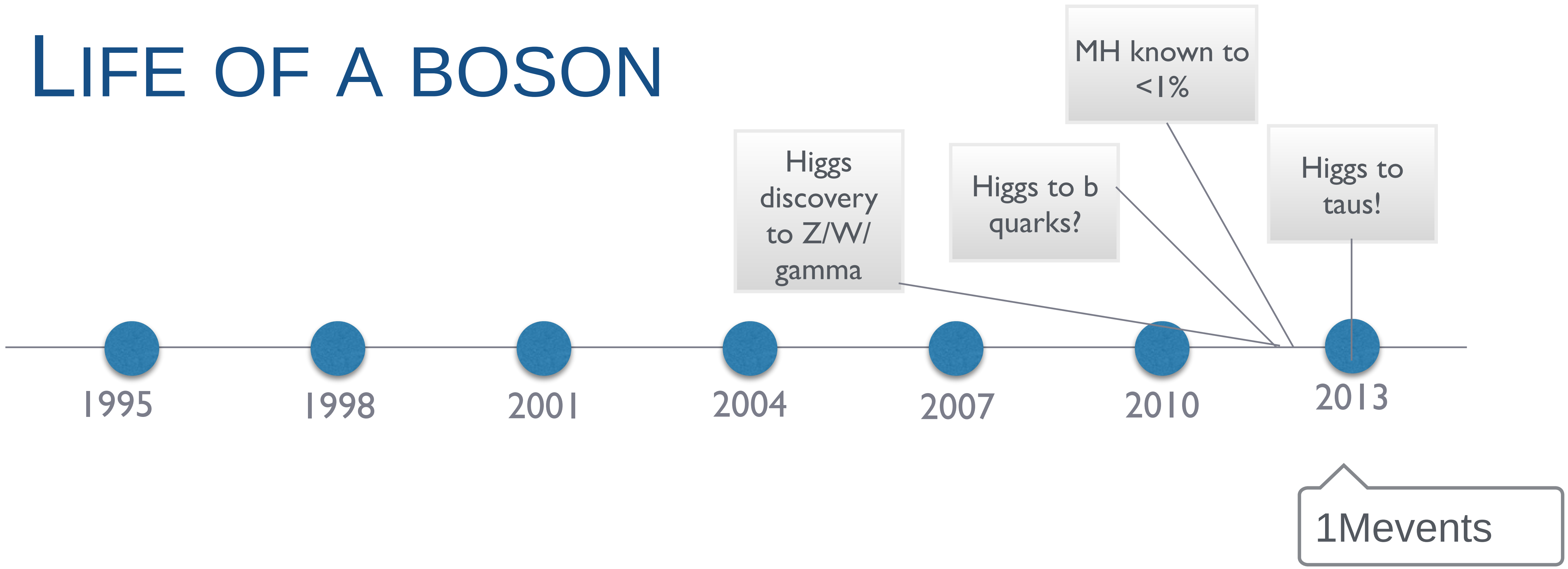
LIFE OF A QUARK



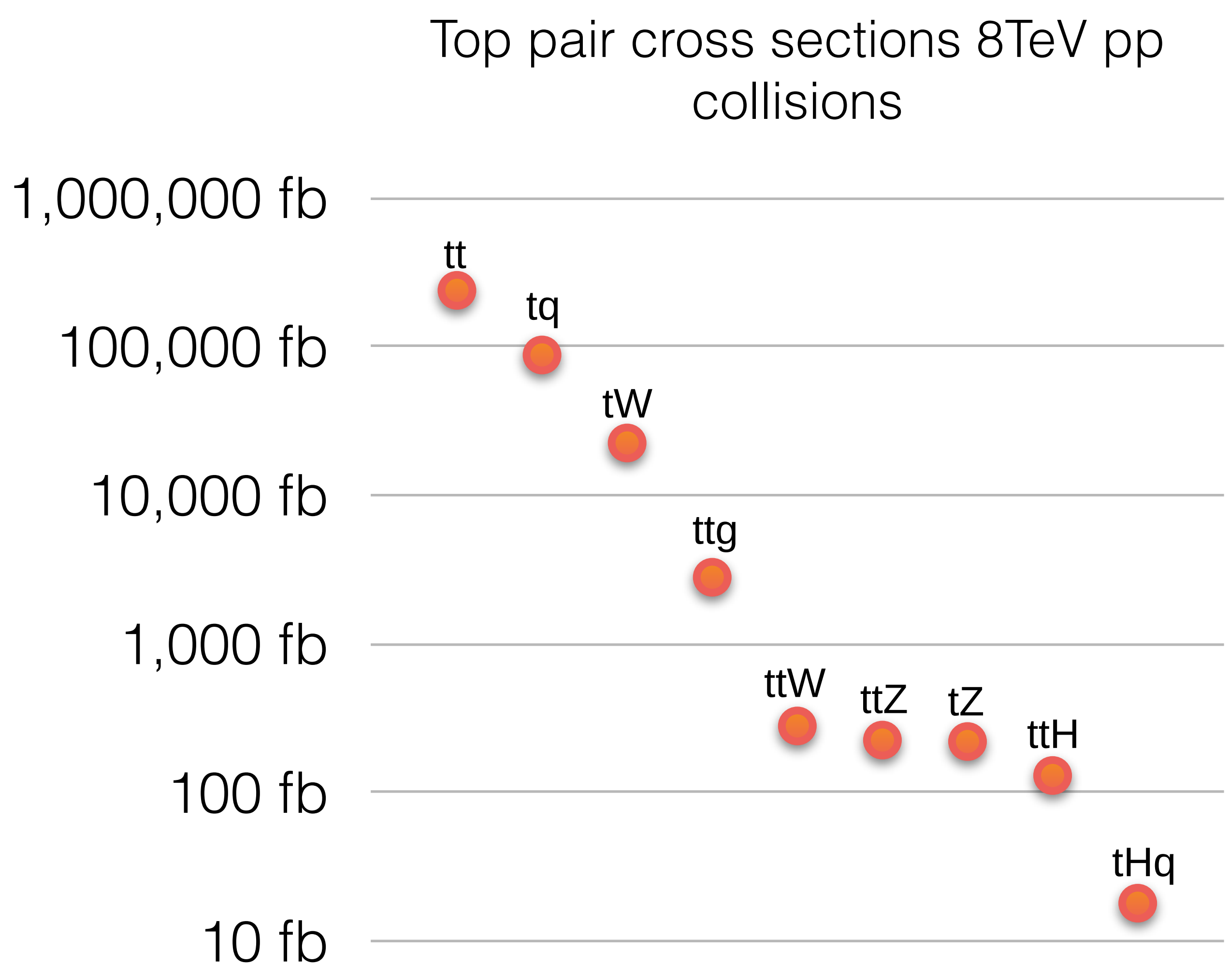
LIFE OF A QUARK

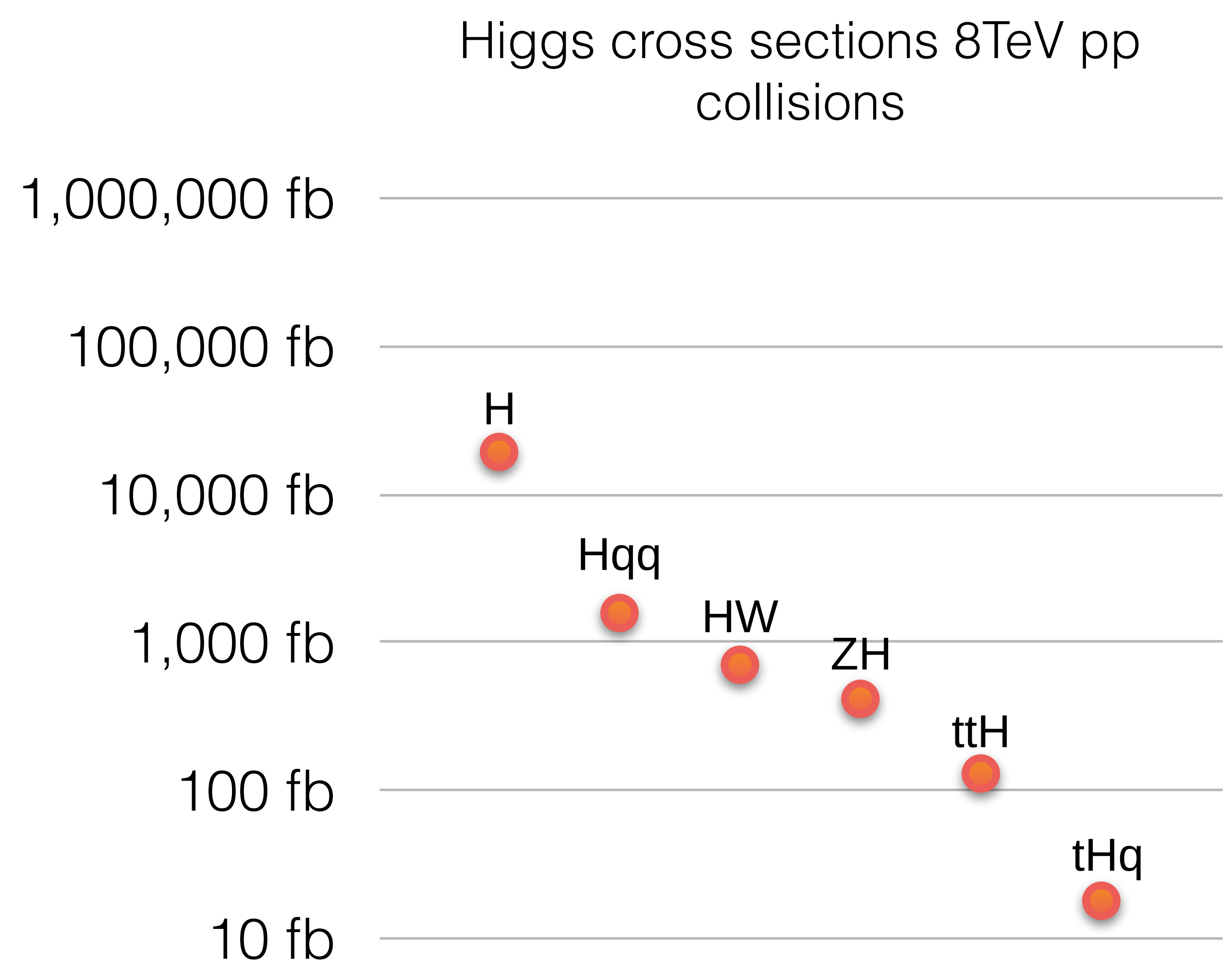


LIFE OF A BOSON



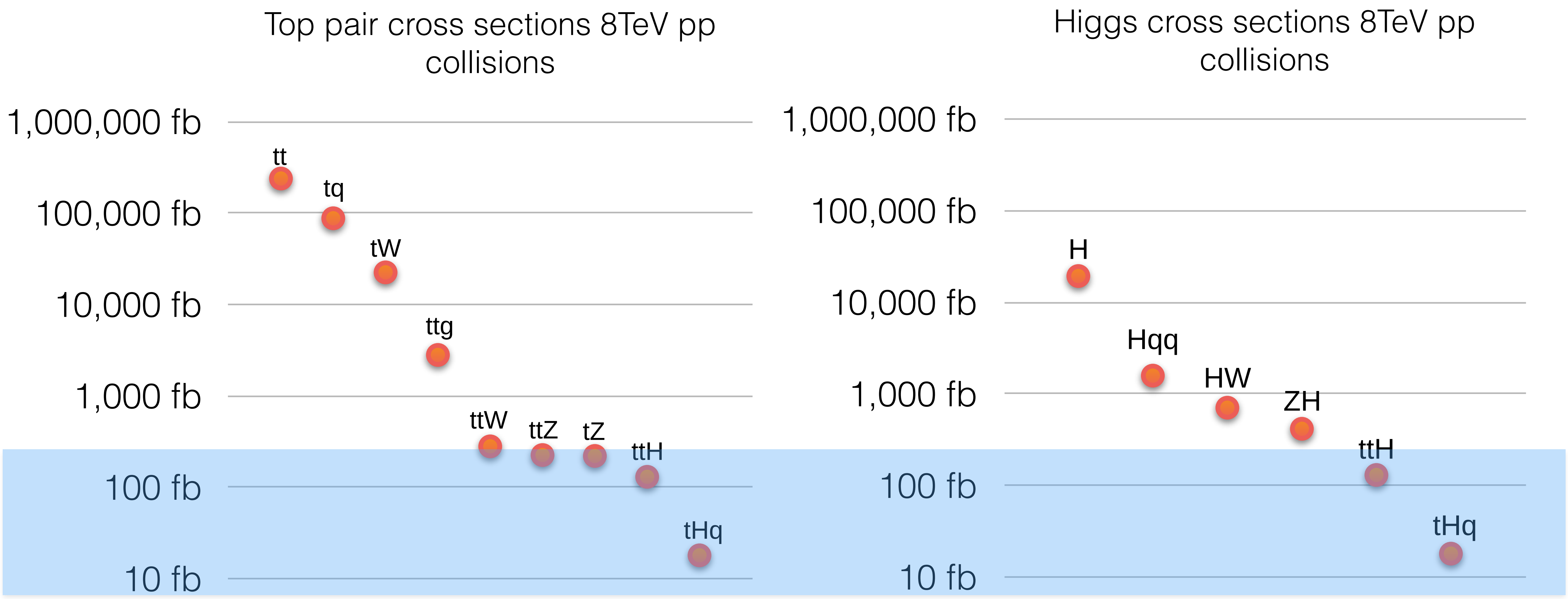
Dig deeper into the LHC gold





t+H is the next goal in both Higgs physics, and in top physics

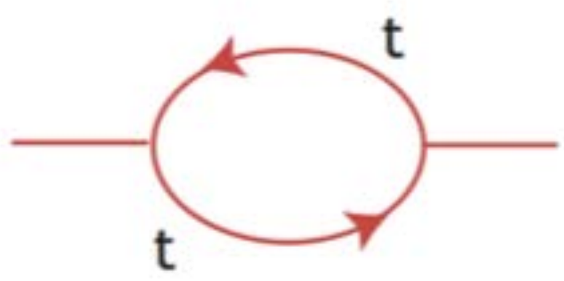
DIG DEEPER INTO THE LHC GOLD



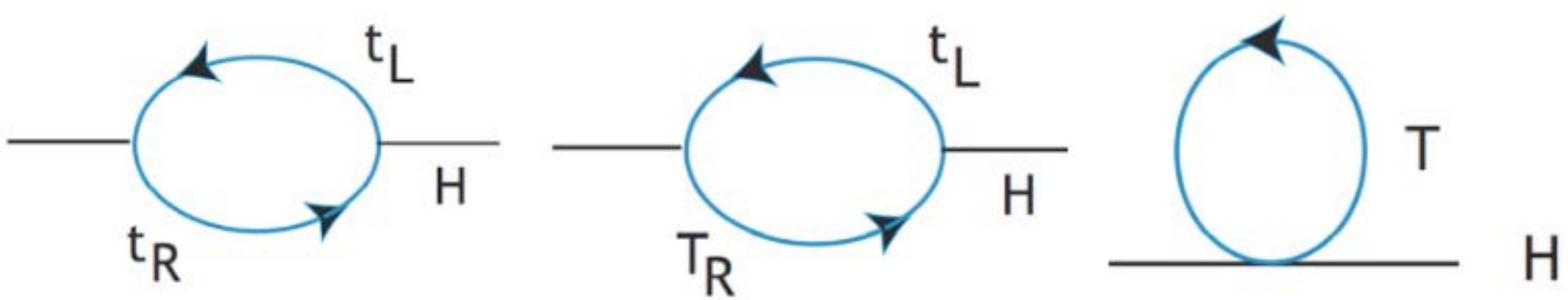
t+H is the next goal in both Higgs physics, <u>and</u> in top physics

TOP PARTNERS REQUIRED

- The large mass of the top quark induces quadratic divergencies

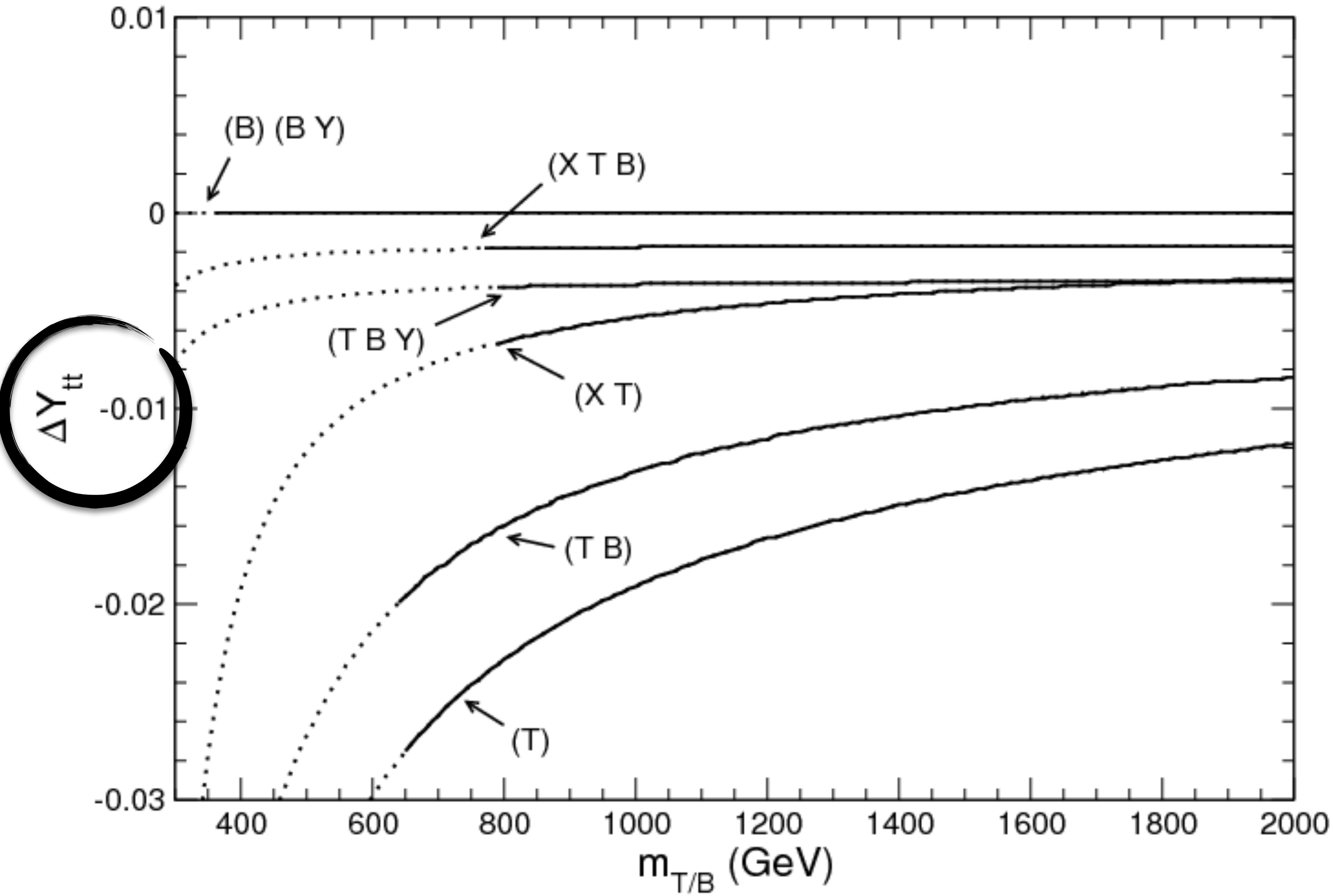


- Both solution to the problem involve hypothesizing the existence of top partners of bosoni (SUSY) or fermionic (Composite Higgs) nature, that automatically cancel such divergencies
- In the fermionic scenario new T particles exist such that T->tH (and T->tZ/Wb) are possible



- and T might be only one of a family of new quarks T/B/X (and bosons too!)

FERMIONIC TOP PARTNERS



- Deviation from Yukawa could be too small to be visible

- both in current and future collider experiments

J.A. Aguilar-Saavedra, R. Benbrik, S. Heinemeyer, M. Pérez-Victoria
arXiv:1306.0572

Fermionic top partners