ICHEP Report, Part I:
The interesting topics

John Keller
on behalf of the ATLAS travel budget

Contents

- Higgs
- Exotics
- Dark matter

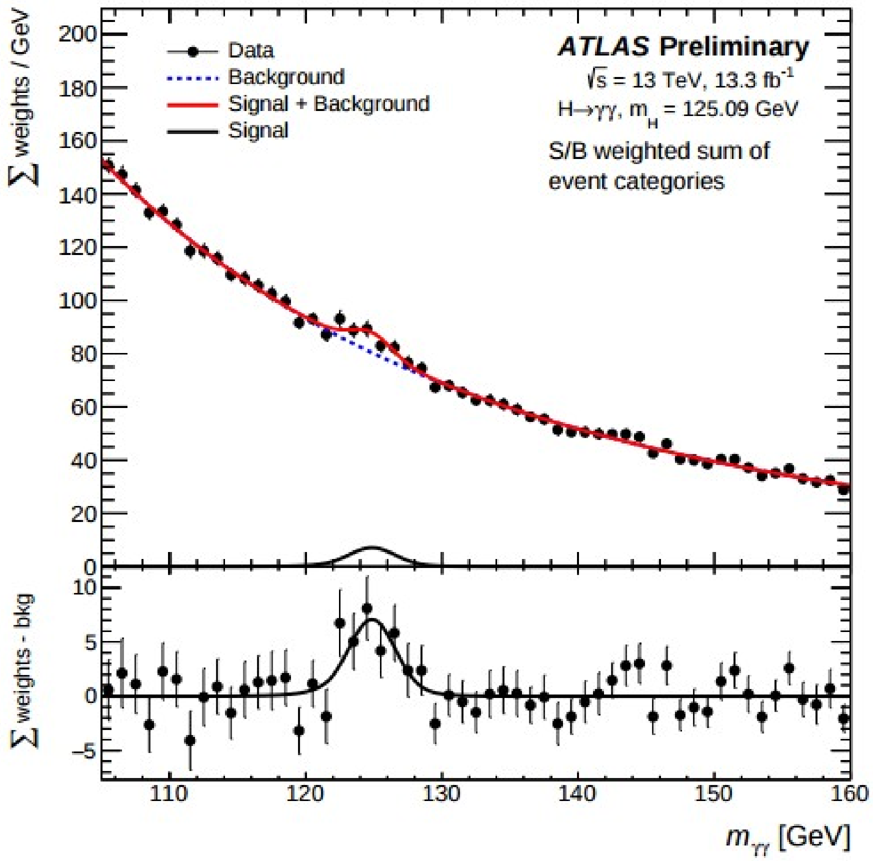
Standard Disclaimer: Lots of talks, can't cover everything, personal selection, etc etc.

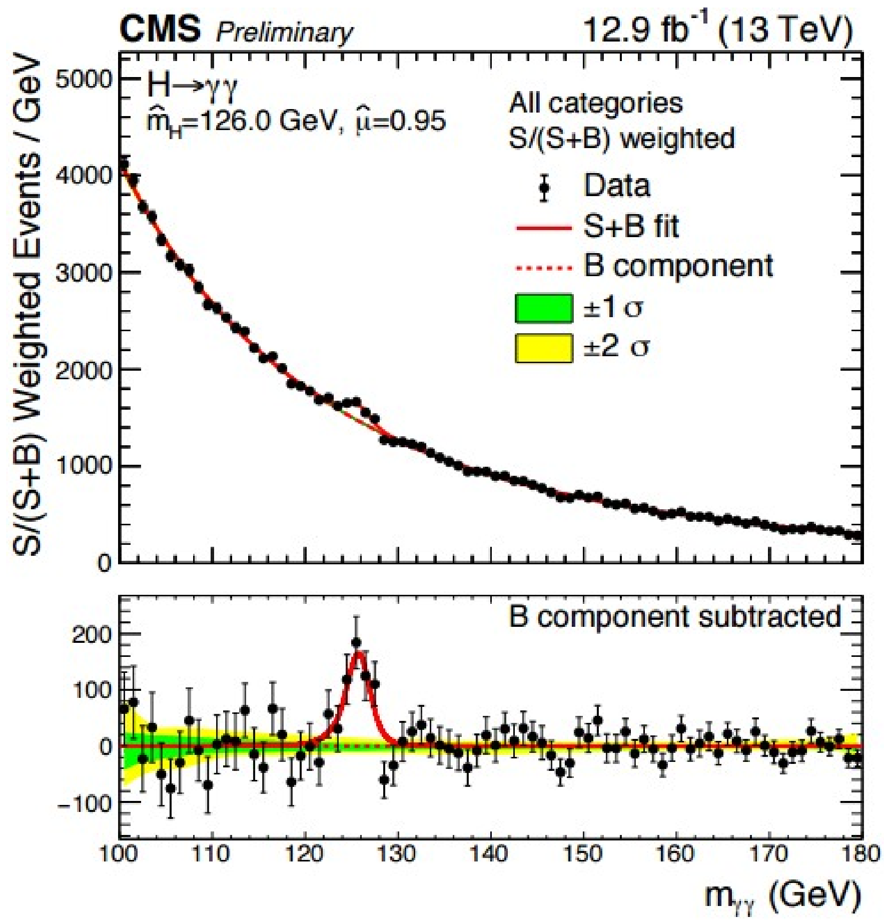
In particular focus on experimental results and (for LHC) those with 2016 data.

SM Higgs: Results with 2016 data

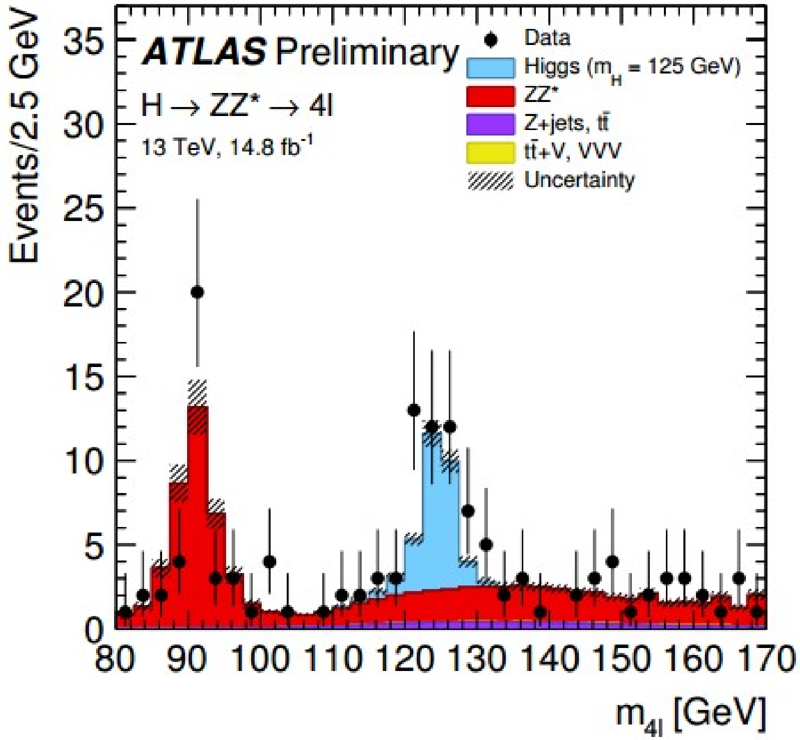
Channel	ATLAS	CMS	Comment
γγ	✓	✓	
ZZ	✓	✓	
WW			A: Talk removed (?)
bb (VH)	✓		A: Also VBF+γ
ττ			
ttH	✓	✓	C: ML & γγ; A: also bb
Couplings	✓	✓	A: ZZ+γγ combination
Mass		✓	C: Only ZZ (sort of)

It's back!

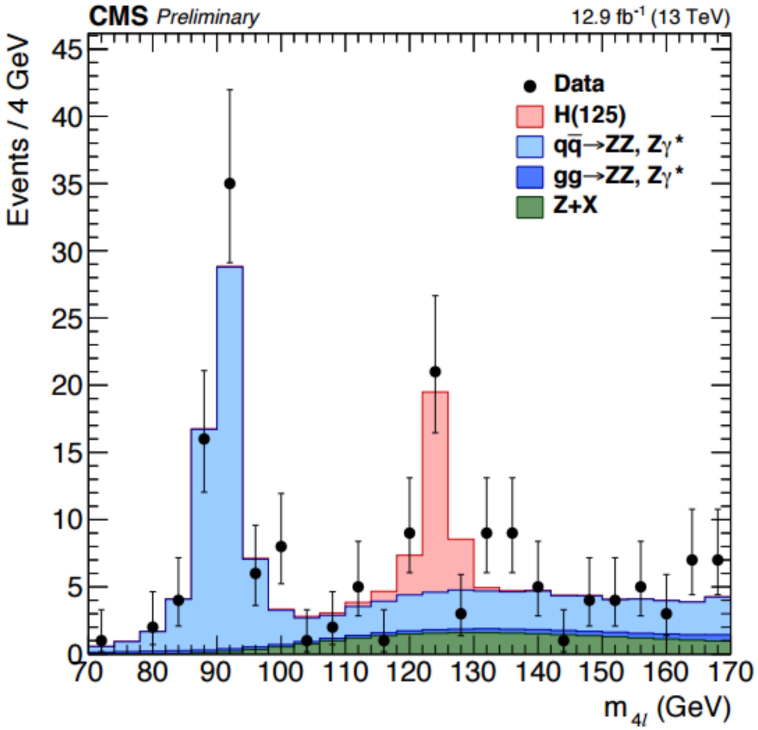

ATLAS Preliminary
√s = 13 TeV, 13.3 fb-1
H→γγ, m_H = 125.09 GeV
S/B weighted sum of
event categories
Data
Background
Signal + Background
Signal
∑ weights / GeV
∑ weights - bkg
m_γγ [GeV]


CMS Preliminary
12.9 fb-1 (13 TeV)
H→γγ
m̂_H=126.0 GeV, μ̂=0.95
All categories
S/(S+B) weighted
Data
S+B fit
B component
±1 σ
±2 σ
S/(S+B) Weighted Events / GeV
B component subtracted
m_γγ (GeV)

It's back!

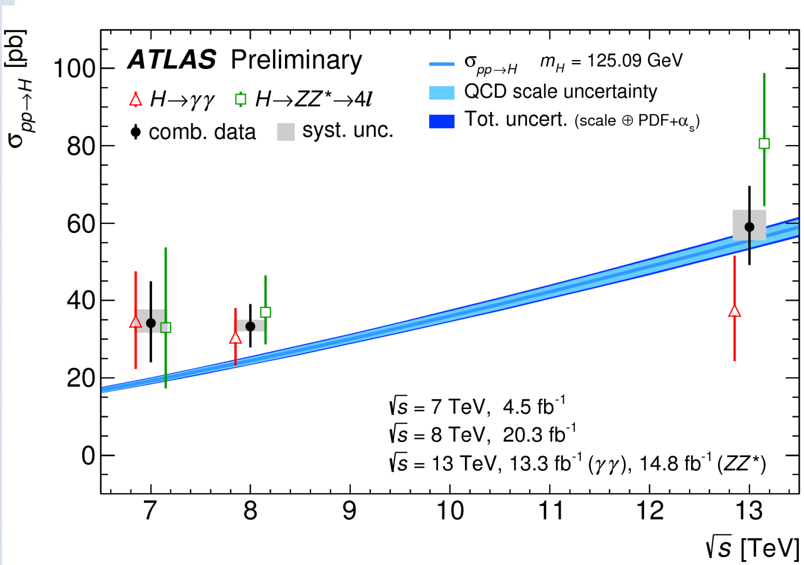


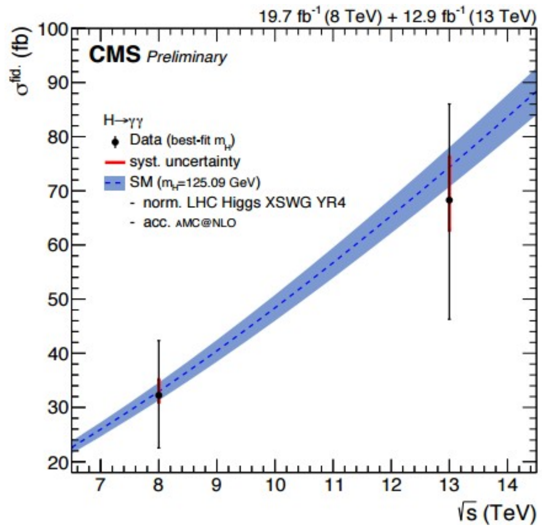
ATLAS Preliminary
H → ZZ* → 4l
13 TeV, 14.8 fb-1
Data
Higgs (mH = 125 GeV)
ZZ*
Z+jets, tt̄
tt̄+V, VVV
Uncertainty
Events/2.5 GeV
m4l [GeV]

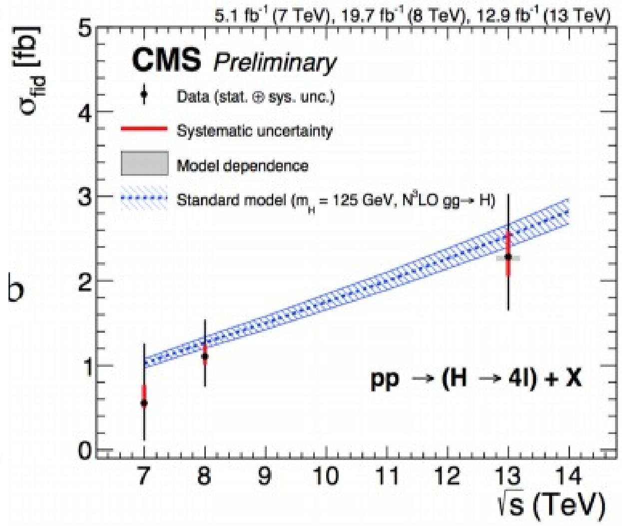


CMS Preliminary
12.9 fb-1 (13 TeV)
Data
H(125)
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
Events / 4 GeV
m4l (GeV)

Cross-sections







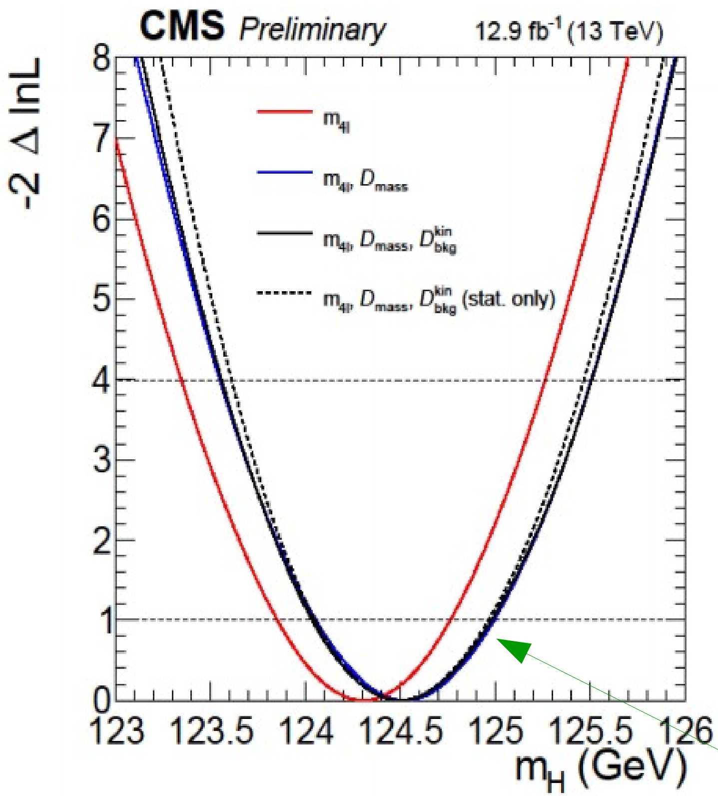
$$\mu = 1.13^{+0.18}_{-0.17}$$

$$\hat{\sigma}/\sigma_{SM} = 0.95^{+0.21}_{-0.19}$$

$$\mu = \sigma/\sigma_{SM} = 0.99^{+0.33}_{-0.26}$$

- Significance: 10σ ATLAS, 6.1σ + 6.2σ CMS.

Mass measurement



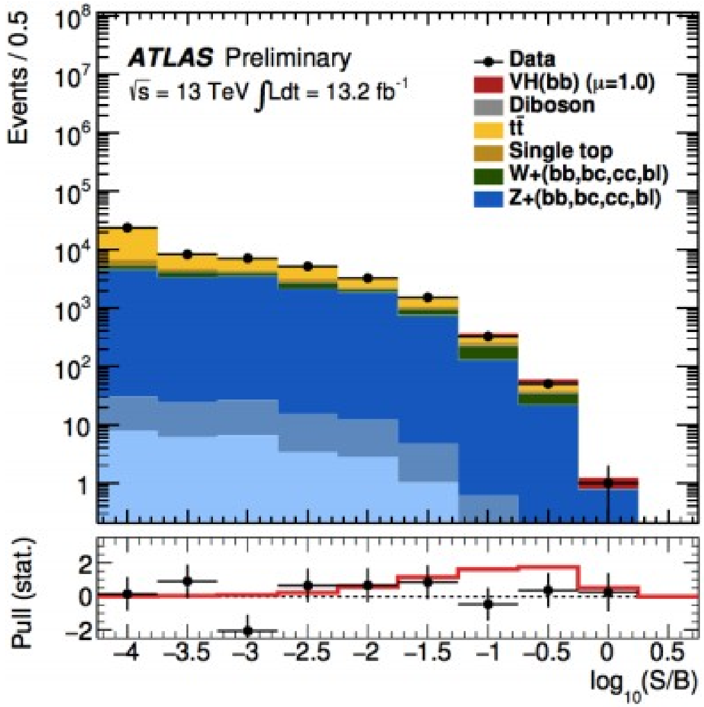
Using 4l 3D measurement, observed $m_H = 124.50^{+0.48}_{-0.46}$ $(stat\ ^{+0.47}_{-0.45}, syst\ ^{+0.13}_{-0.11})$ GeV

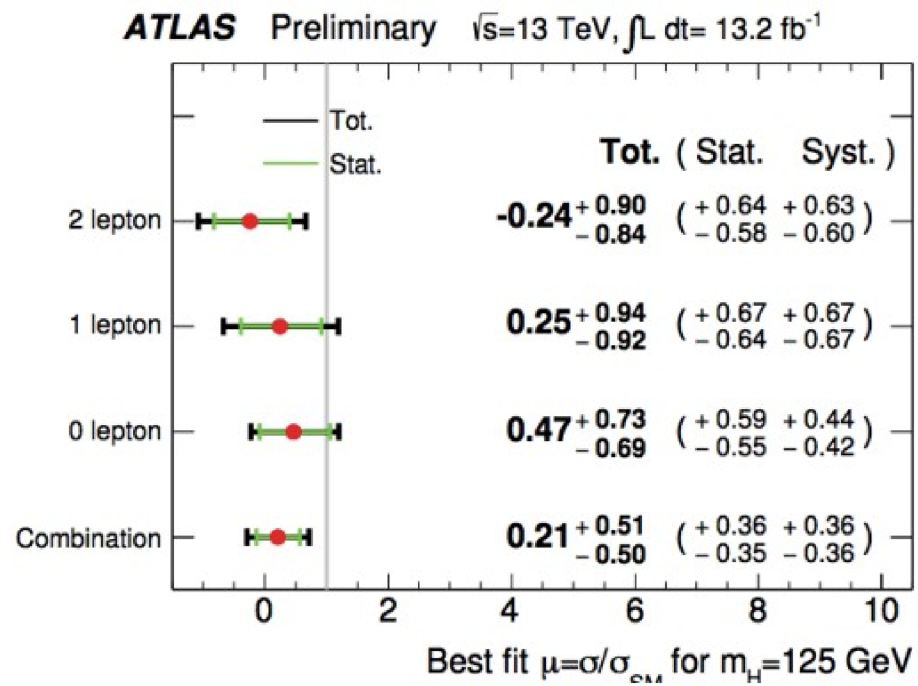
$\gamma\gamma$ observed best-fit:
$m_H = 126.0$ GeV
→ Stat. unc. ~0.3 GeV
→ Syst. unc. ~0.2-0.4 GeV

resolution improved using lepton-by-lepton uncertainties.

- The Run 1 mass discrepancy has returned! And switched experiments!

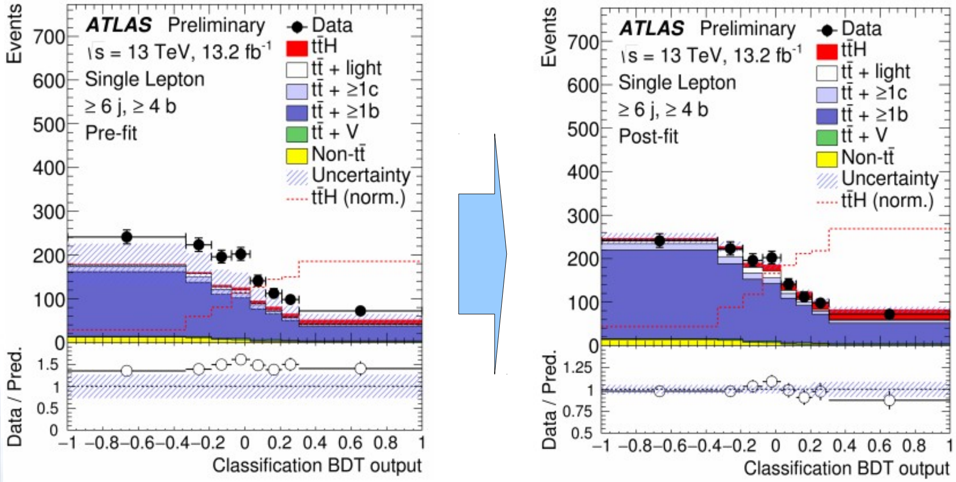
VH → bb



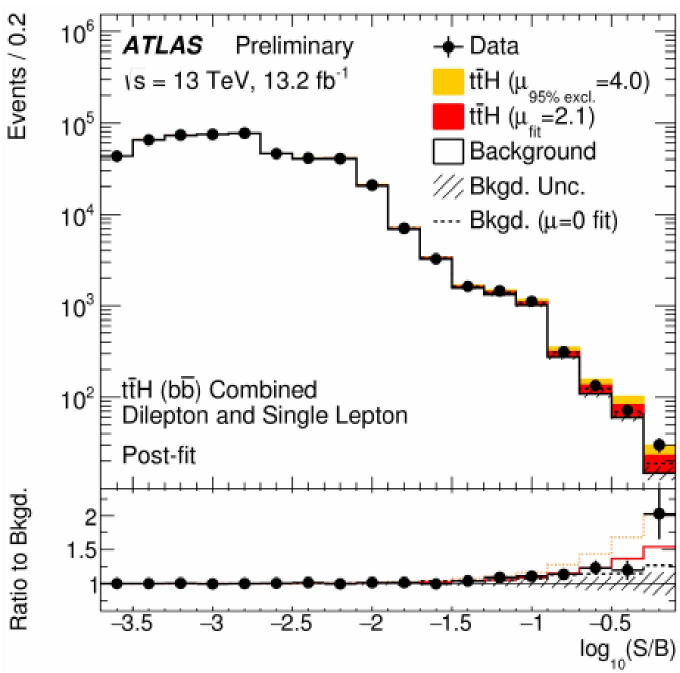


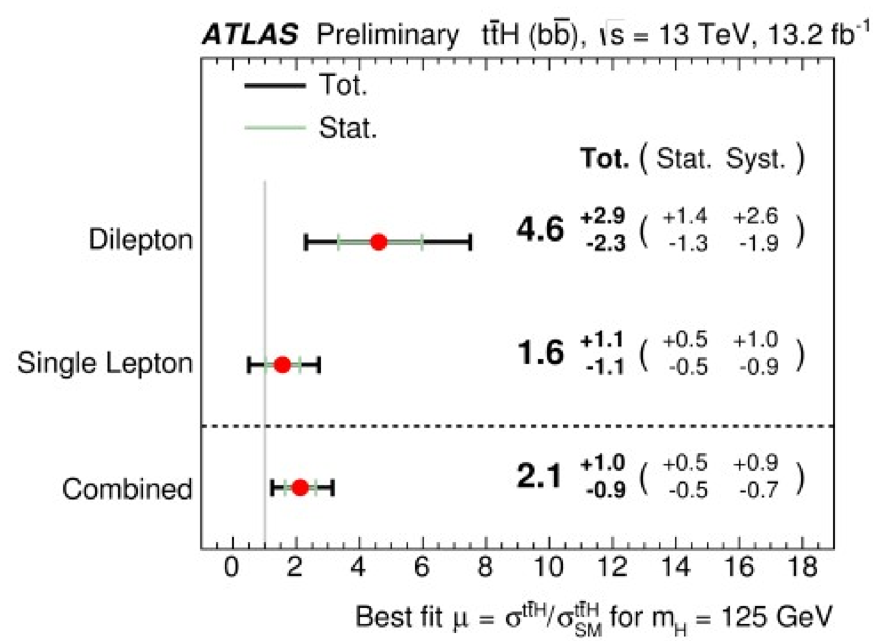
- Combined best fit from Run 1 was 0.7 +/- 0.3.
  - Start to get interested if CMS is low in Run 2 as well.
- Diboson VZ(bb) measurement consistent with the SM.

ttH (bb)



- ttH: Direct measure of top Yukawa, test SM consistency.
- Multi-region MVA fit.
- 2015 CMS result: similar analysis, mu = -2.0.

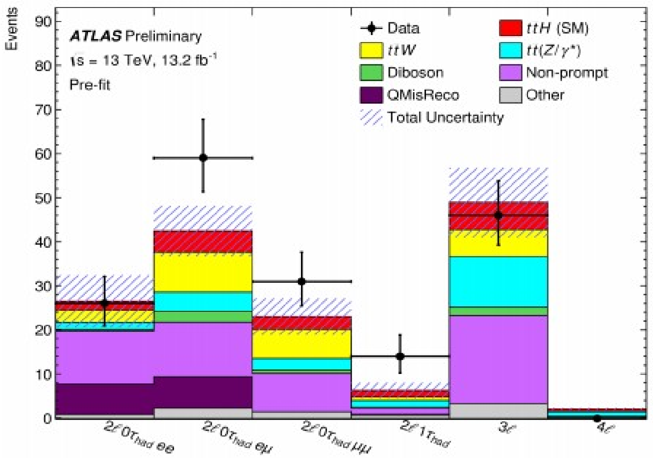


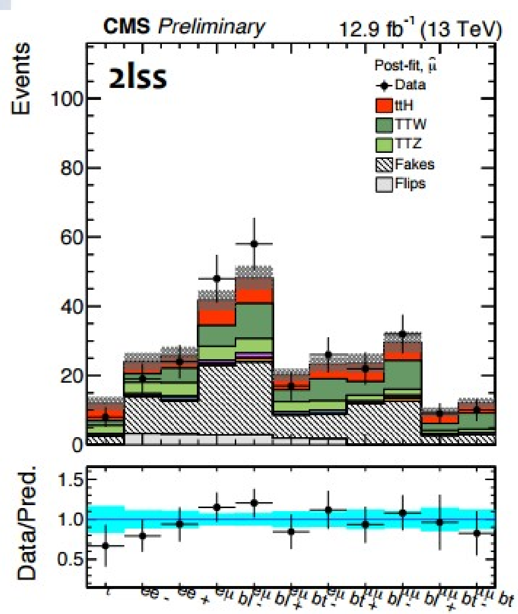


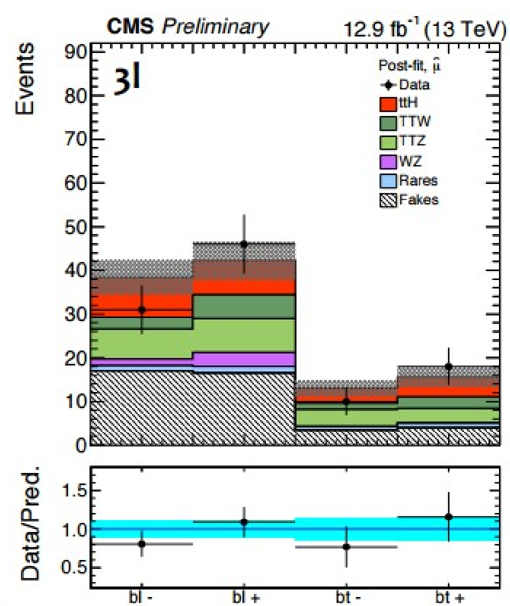
ttH (Multilepton)

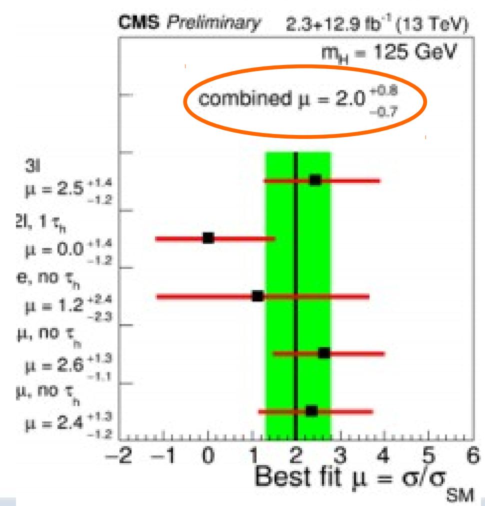
- Many Higgs decays give similar multi-lepton final states: focus on those with high S/B.
- ATLAS: Counting analyses.
- CMS: 2D fit of separate BDTs against tt and ttV in each region.

Category	Higgs boson decay mode WW^*	$\tau\tau$	ZZ^*	Other	$A \times \epsilon$ $(\times 10^{-4})$
$2\ell 0\tau_{had}$	77%	17%	3%	3%	14
$2\ell 1\tau_{had}$	46%	51%	2%	1%	2.2
3ℓ	74%	20%	4%	2%	9.2
4ℓ	72%	18%	9%	2%	0.88









ATLAS:

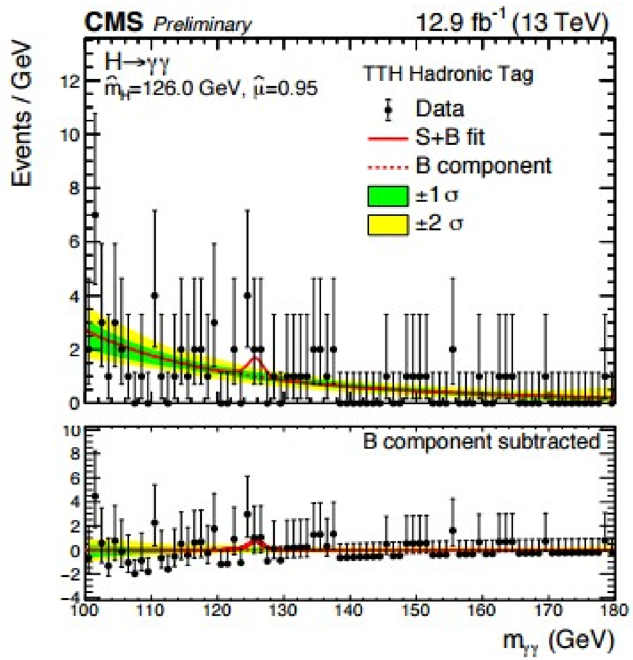
$2.5\ ^{+1.3}_{-1.1}\ \left(^{+0.7}_{-0.7},\ ^{+1.1}_{-0.9}\right)$

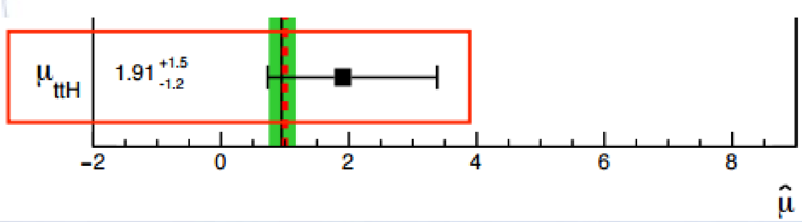
ttH (γγ and combination)

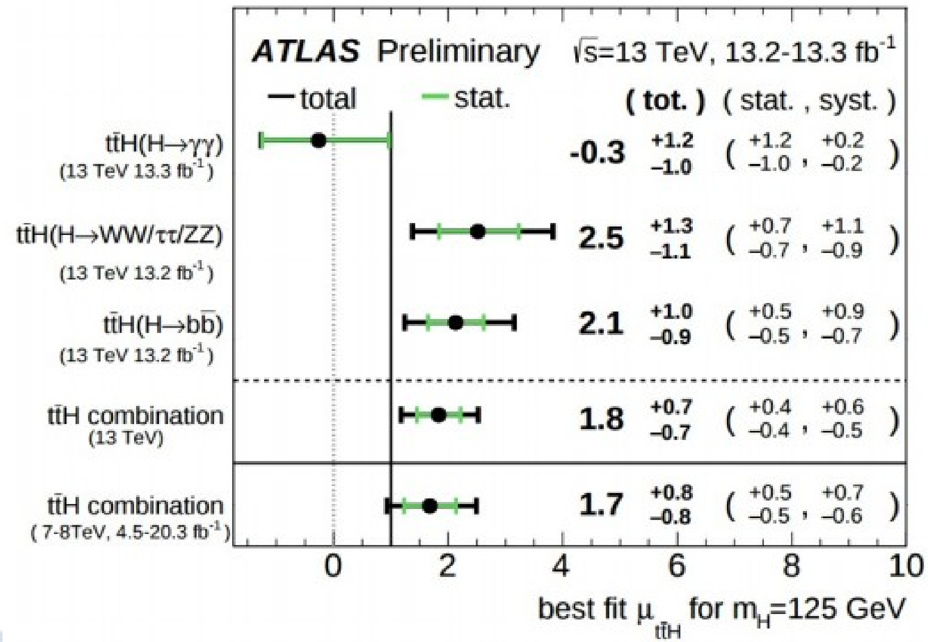
- ttH categories in γγ coupling analyses.
- ATLAS: combination of 3 final states (similar sensitivity to CMS multilepton).

"This is the most important result to keep an eye on from the LHC."

- Carlos Wagner (important dude)

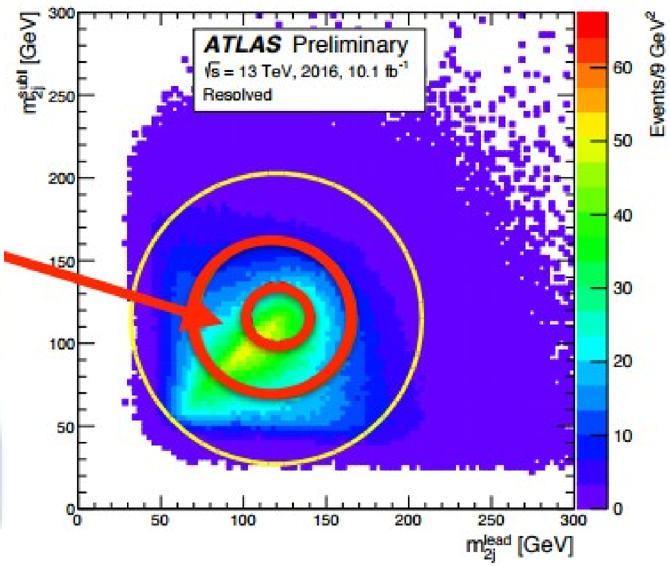


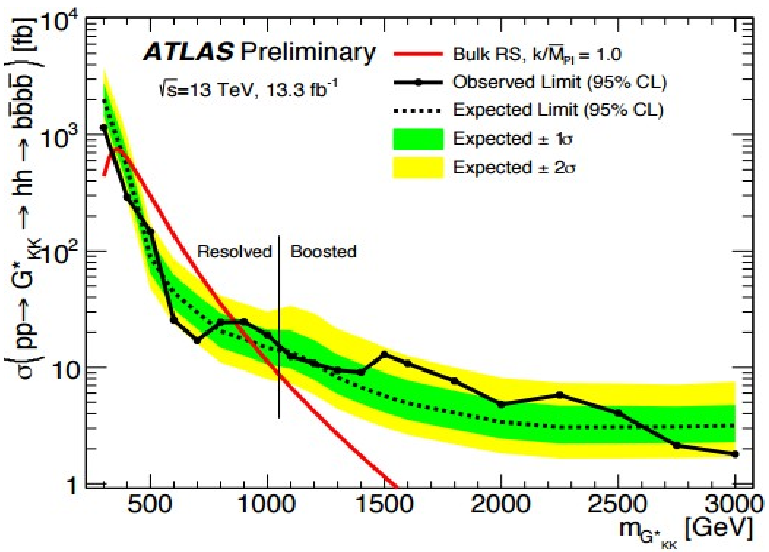




Di-Higgs: ATLAS

- Di-Higgs: Access to self-coupling (non-resonant) or new heavy resonance (e.g. MSSM H→hh).
- 4b analysis: Including boosted analysis with b-tagged specialized b-tagging algorithms.
- Increasingly looking like this will dominate sensitivity, but keep an eye on the branching ratio measurement.
- Also, not-so-sensitive WWγγ analysis.





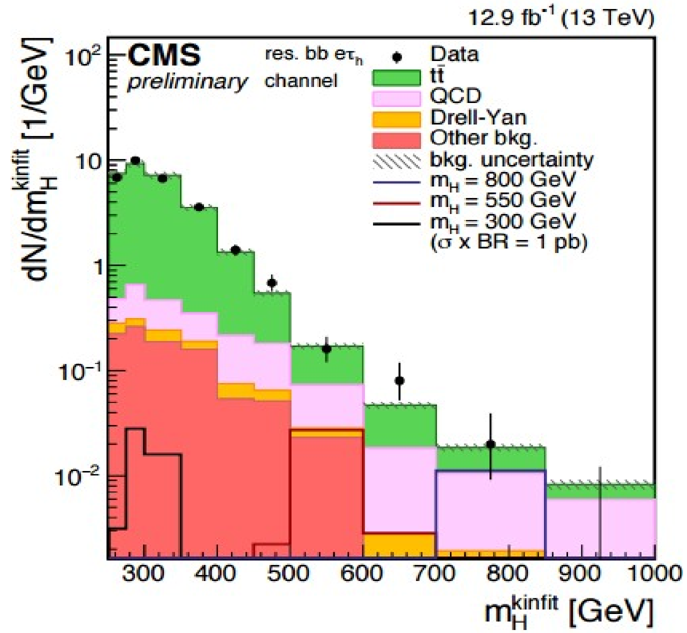
Non-resonant Search:
Only in resolved analysis
σ(pp→hh→bbbb) < 330 fb
(SM prediction = 11.3 fb)

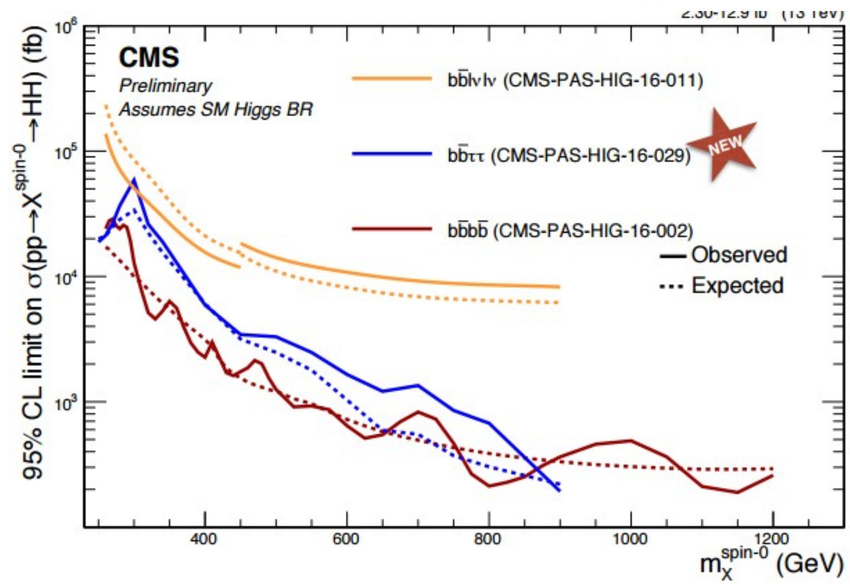
WWγγ

Non-resonant Search:
σ(pp→hh) < 25.0 pb
(expected limit = 12.9 pb)

Di-Higgs: CMS

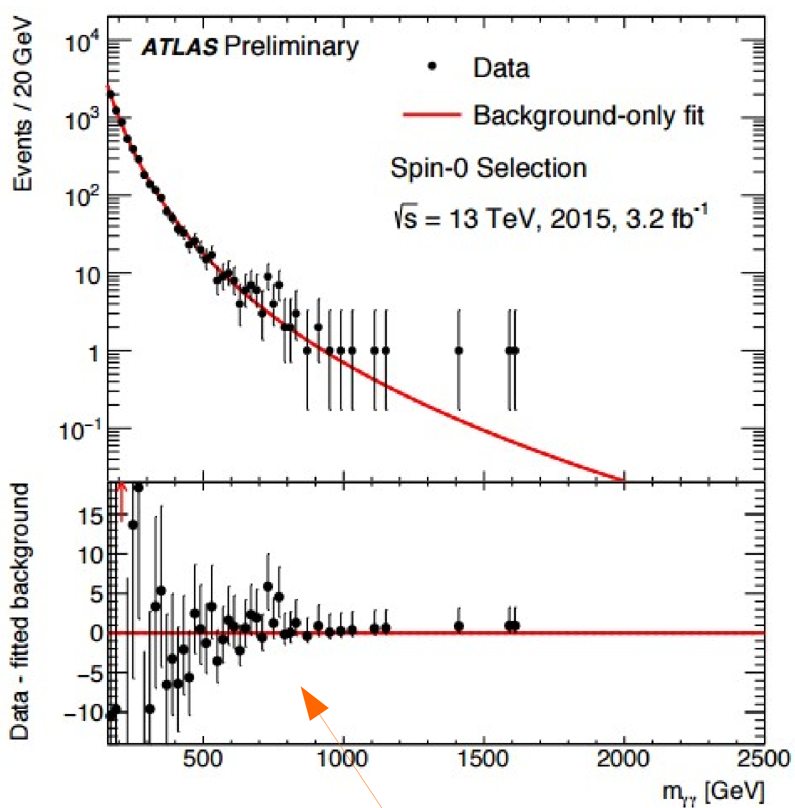
- bbττ: decent branching ratio, tricky objects in final state.
- All ττ decay modes considered, mass reconstructed with kinematic fit.
- Competitive resonant limits for intermediate masses.
- Non-resonant bbWW: low sensitivity but good job trying.

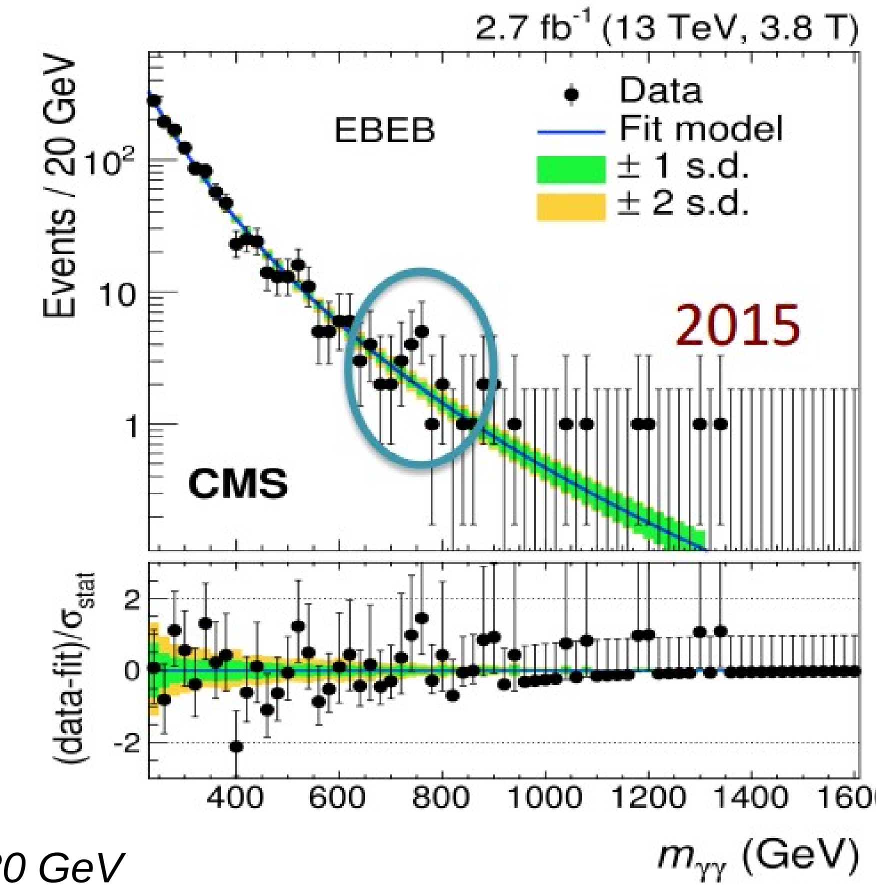




Non-resonant production exclusion	
bbWW	410 X σ(SM) NEW
bbττ	200 X σ(SM) NEW
bbγγ	74 X σ(SM) (Run I)

Exotics: Diphoton

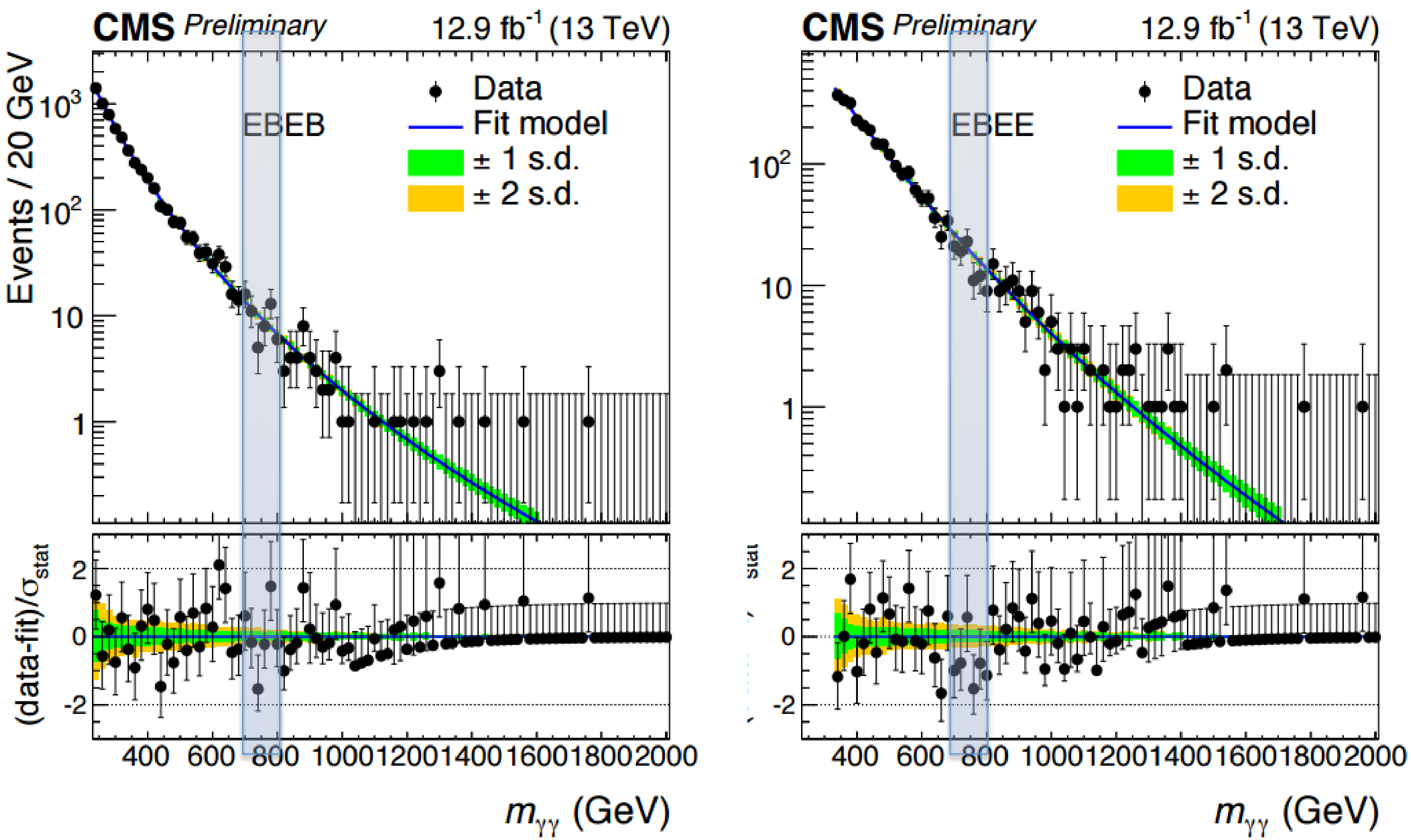




re-analyzed, best-fit mass now 730 GeV

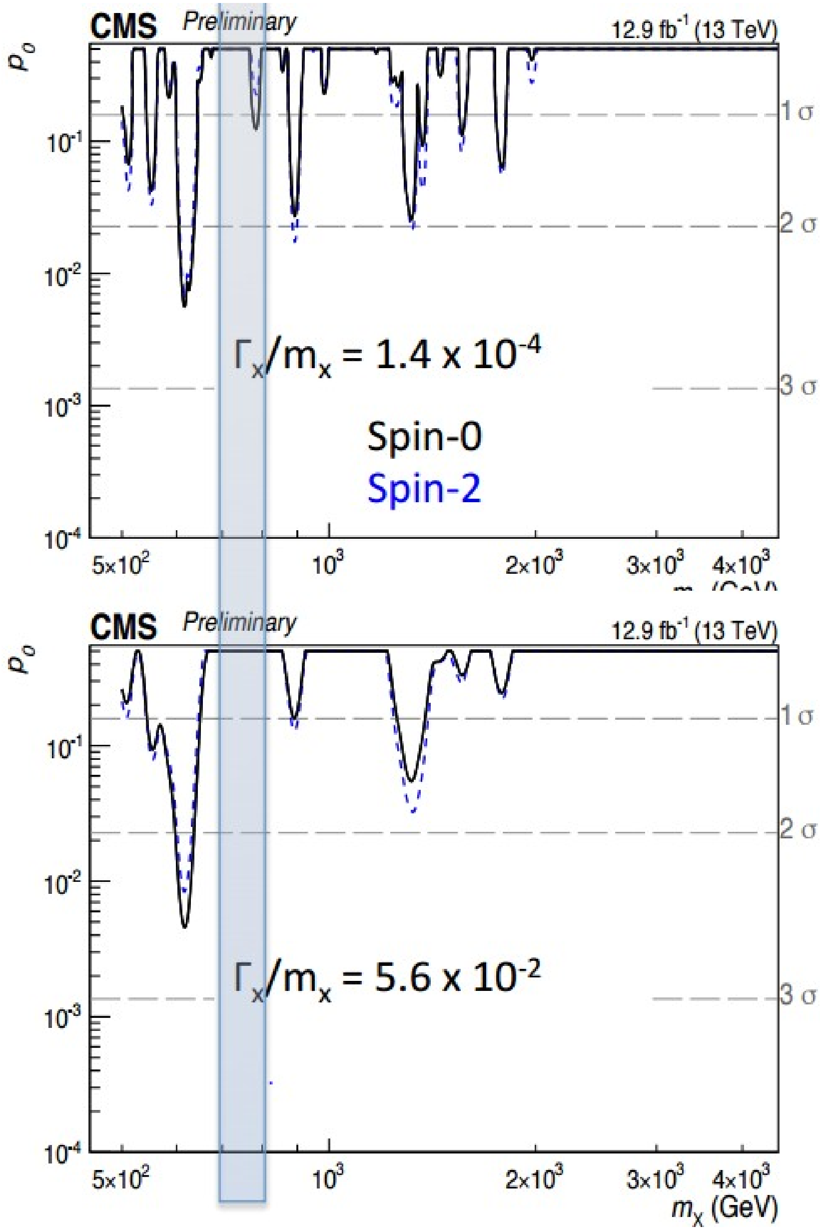
- Recap of 2015 results.
- ATLAS strategy: separate optimizations for spin-0, spin-2.
- CMS strategy: separate barrel-barrel and barrel-endcap.

Diphoton: CMS



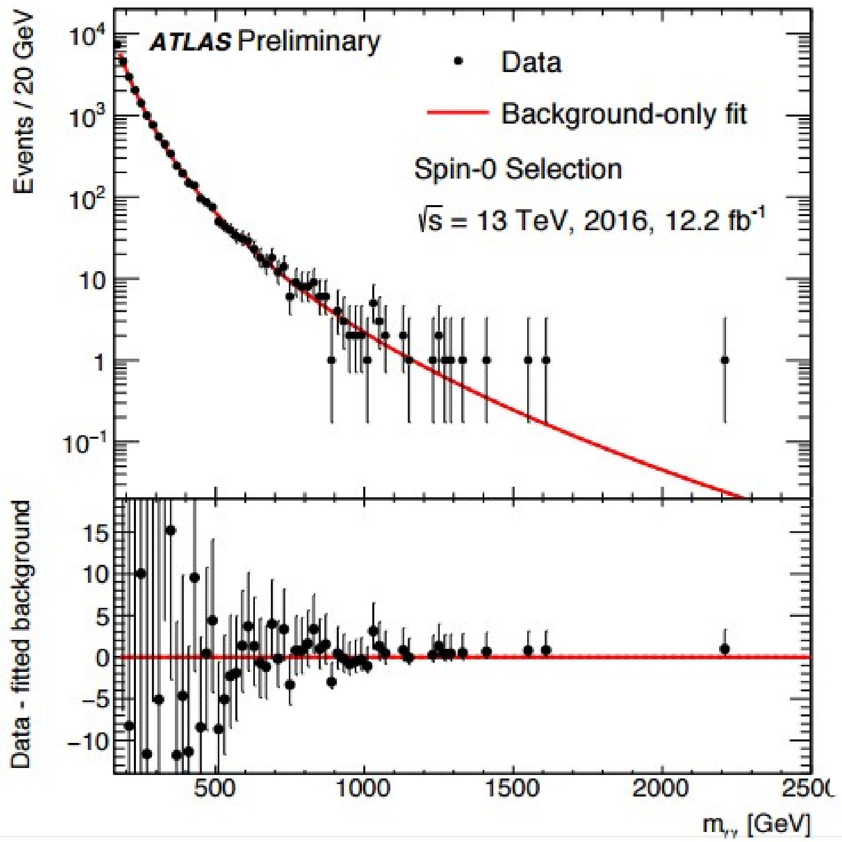
- Sizeable deficit at 750 GeV.

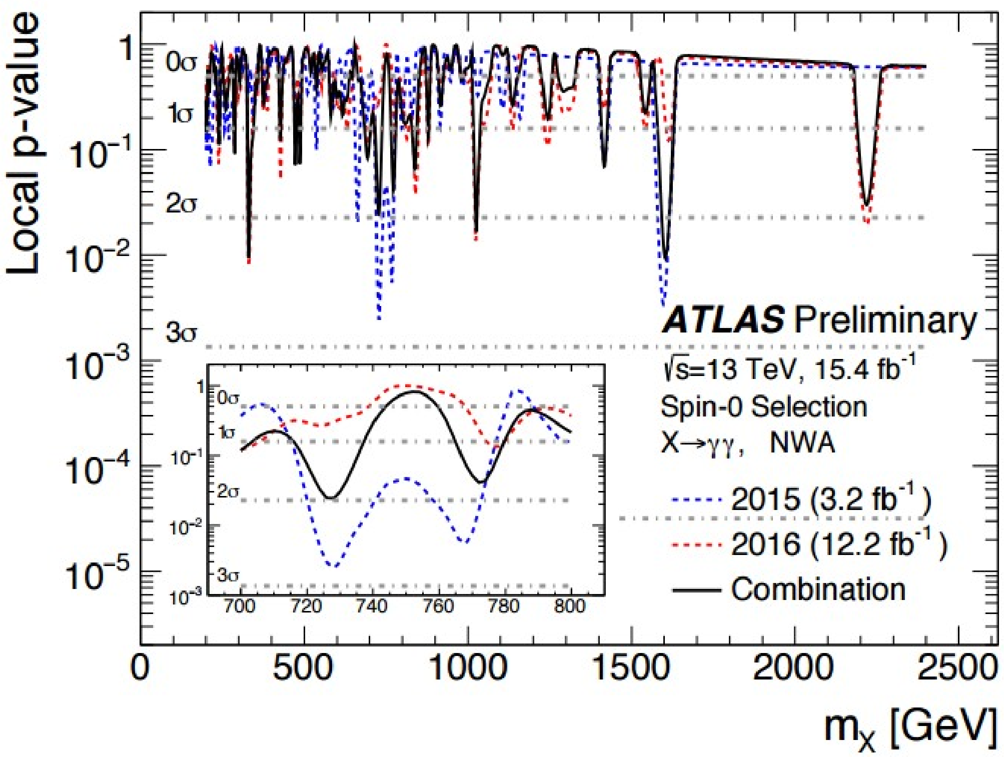
Diphoton: CMS



- New largest excess: ~2.5 sigma at 620 GeV.
- Compatibility of new data:
  - 2.7σ with 2015
  - 2.4σ with 2015 + 8 TeV

Diphoton: ATLAS



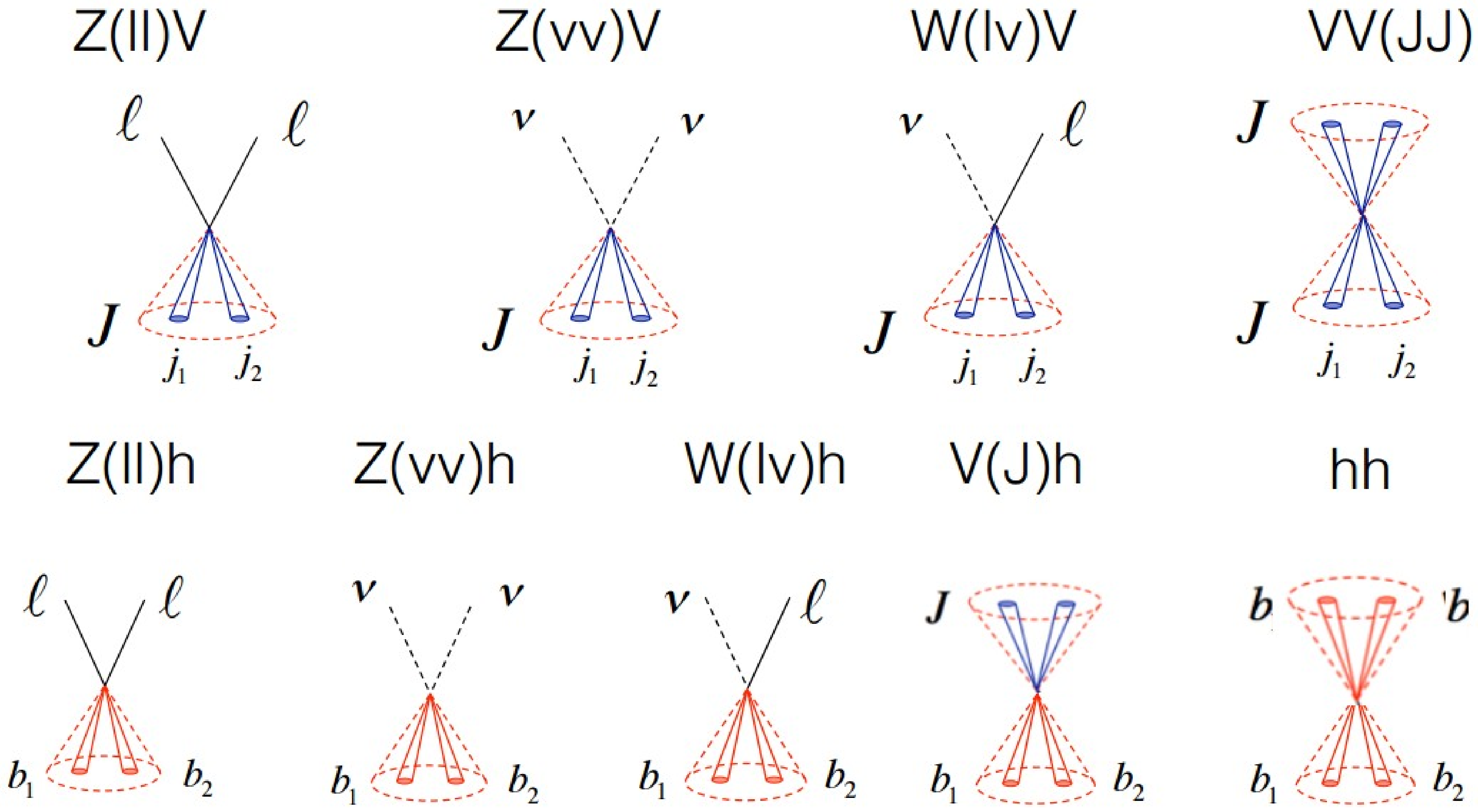


- Compatibility with 2015 data: 2.7 sigma.
- Largest combined excess now at 1.6 TeV; no support for CMS 620 GeV excess.

Diphoton: questions from audience

- ATLAS: What about your spin-2 analysis?
  - Larger kinematic acceptance means it takes longer to understand the data, but we'll have it for you soon.
- CMS: Why no endcap-endcap category?
  - It would not add much to the expected sensitivity. We checked these events in 2015 and mumble mumble, but we haven't looked in 2016.
- Do not throw out your anomalously forward, spin-2 pheno model just yet.

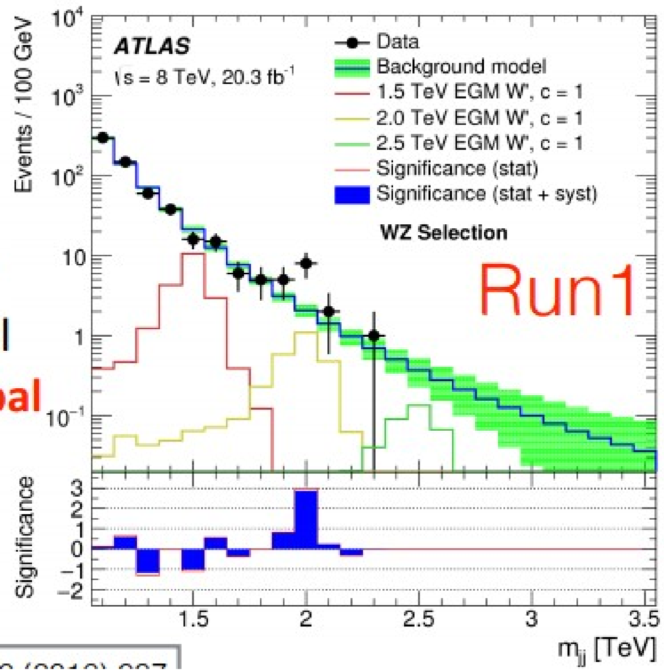
Other dibosons

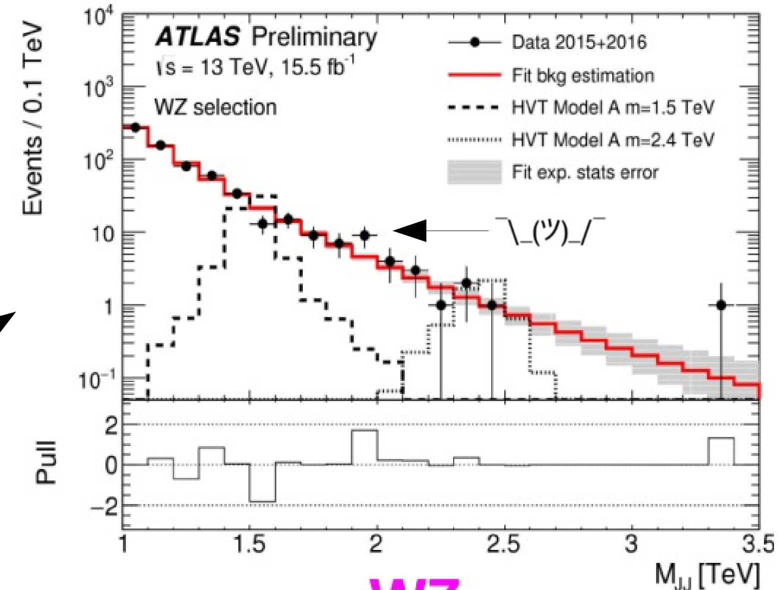


- Lots of final states, lots of special techniques (jet substructure, etc.)

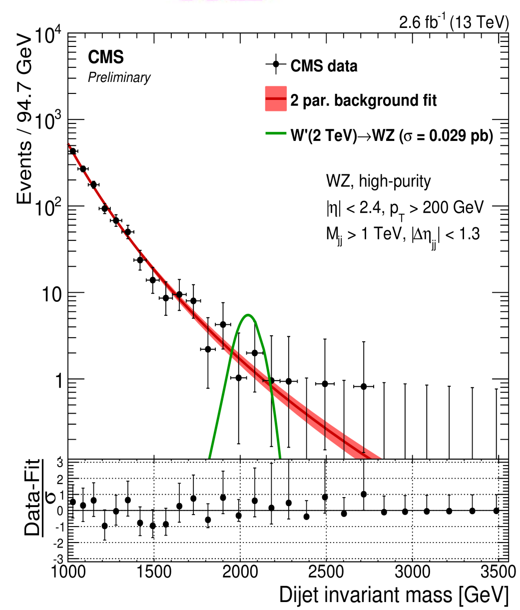
Diboson: VV all-hadronic

m= 2TeV
3.4σ local
2.5σ global



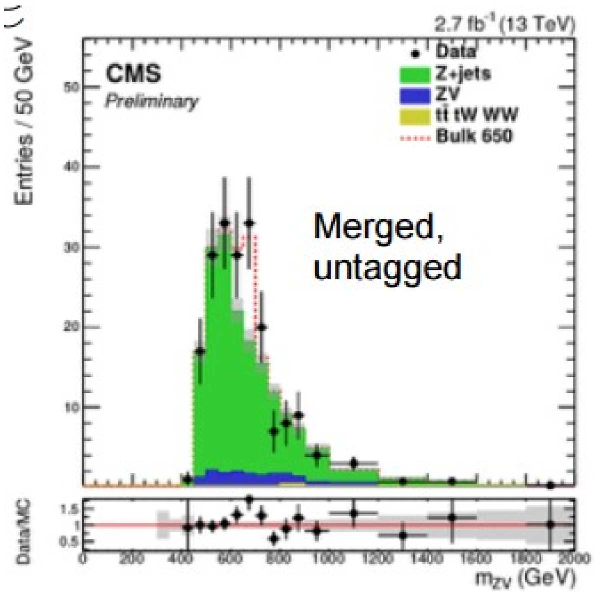


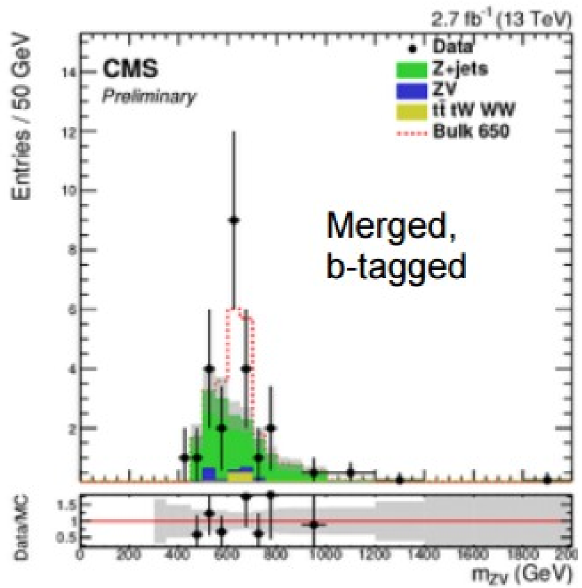
WZ

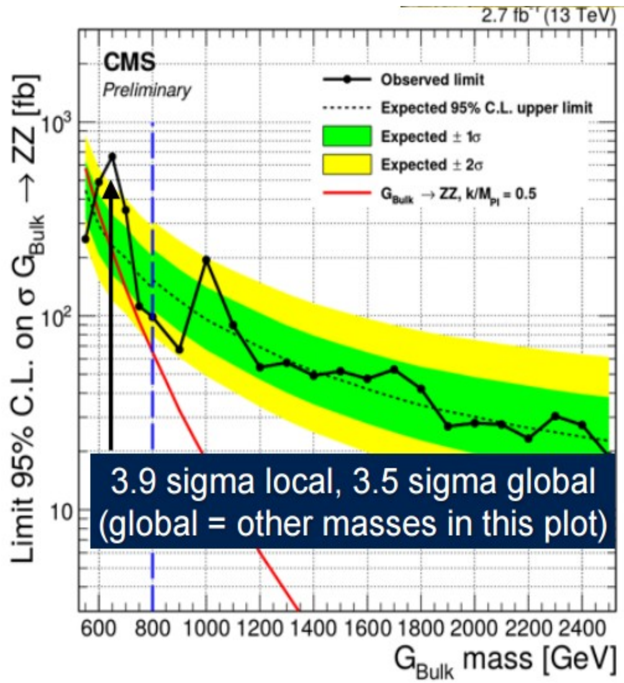


- Looks like the Run 1 excess not confirmed in run 2.

Diboson: CMS VZ

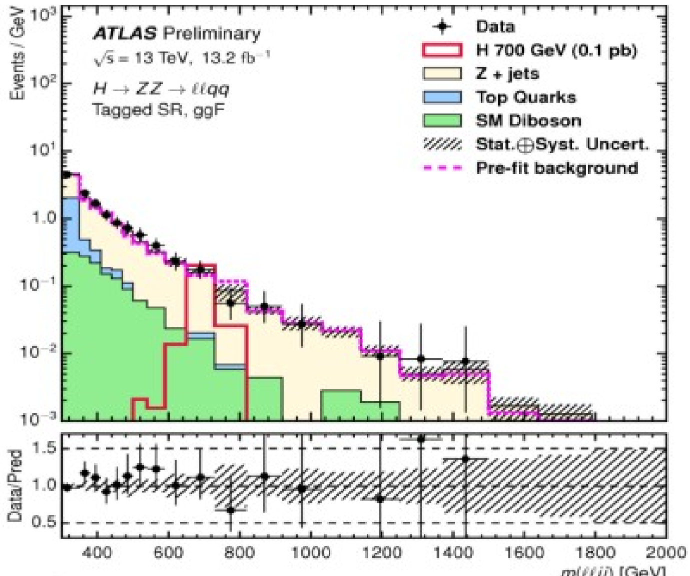


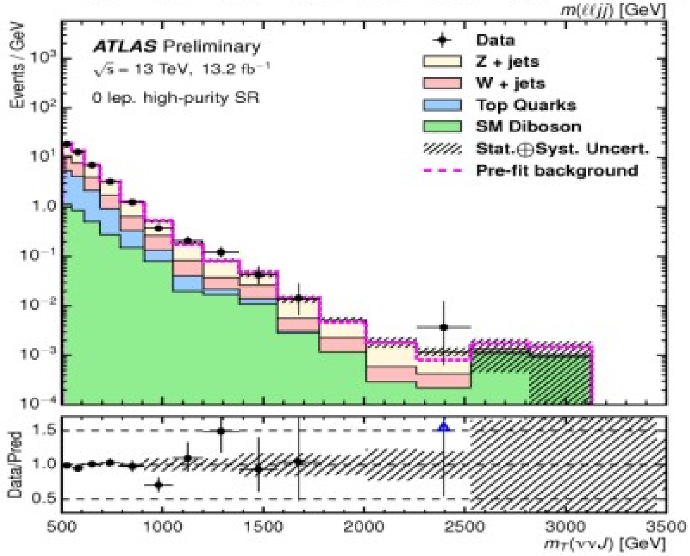




- 650 GeV: the new 750 GeV.
- Note, only 2015 data.

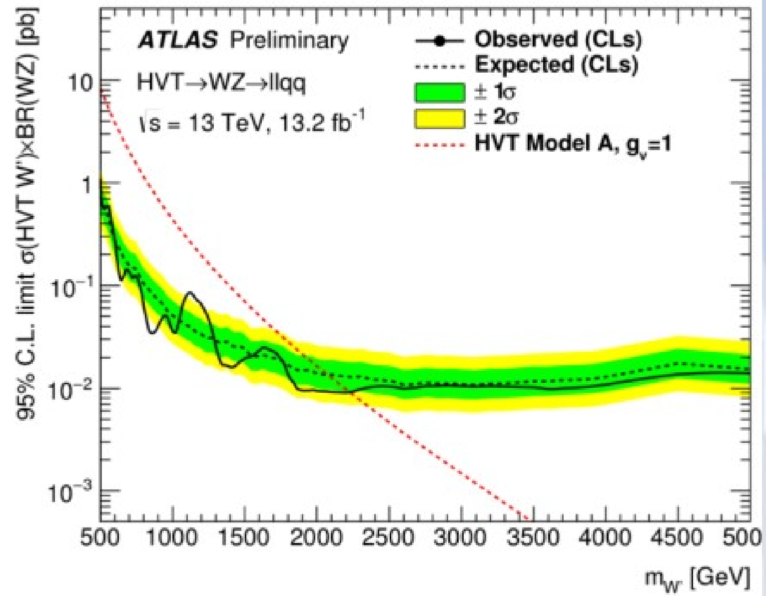
Diboson: ATLAS VZ

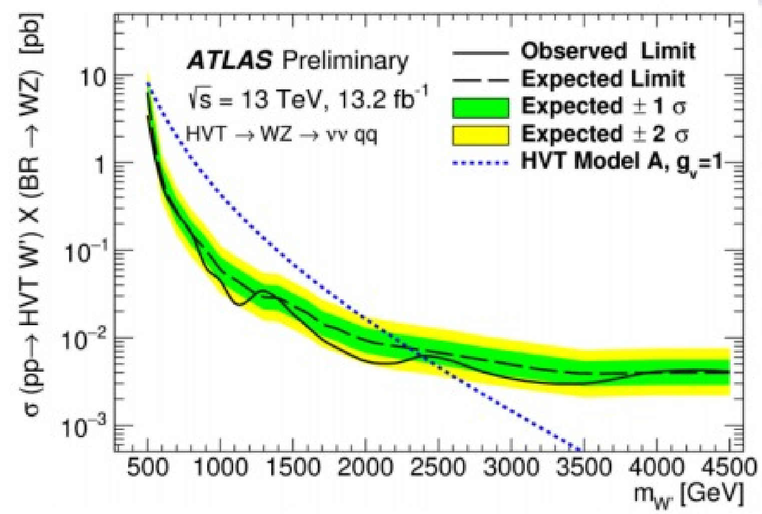




No excess observed in data over the predicted background

Sensitivity to $\sigma \times$ BR down to a few fb for m_X above 2 TeV



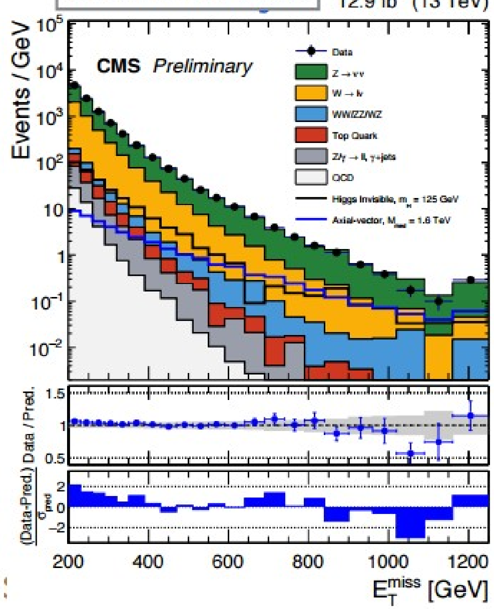


Dark matter at LHC

- 3 main strategies: Invisible Higgs, SUSY, and Mono-anything.
- Background: Almost always Z → νν, either with the other object or mis-reconstructed jets.

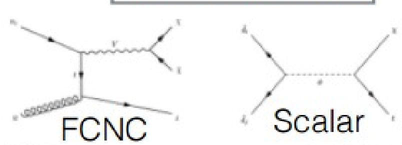
ET^{miss}+jet

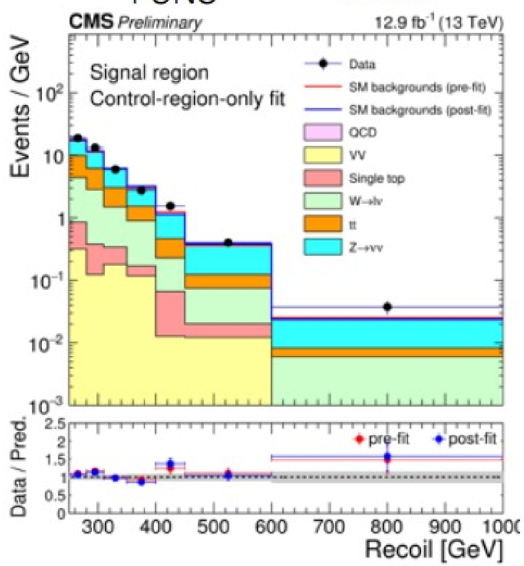
CMS-PAS-EXO-16-037



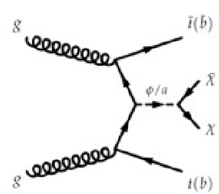
ET^{miss}+t

CMS-PAS-EXO-16-040





$ET^{miss}+b\bar{b}/t\bar{t}$

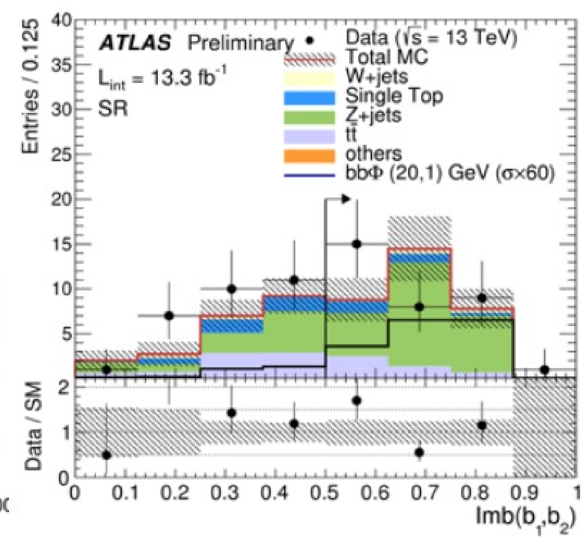


ATLAS-CONF-2016-050

ATLAS-CONF-2016-076

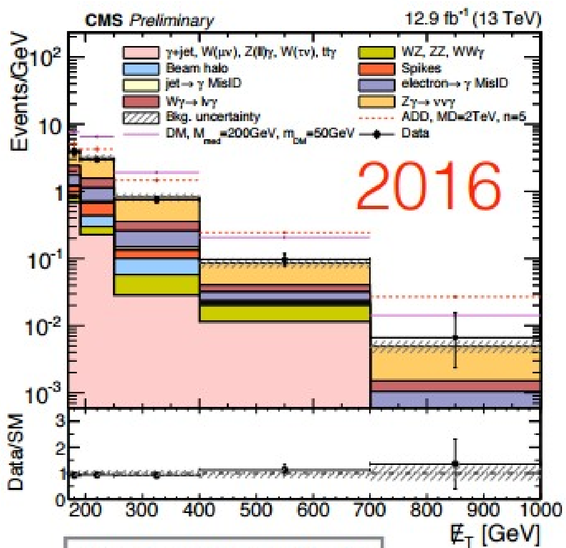
ATLAS-CONF-2016-077

ATLAS-CONF-2016-086



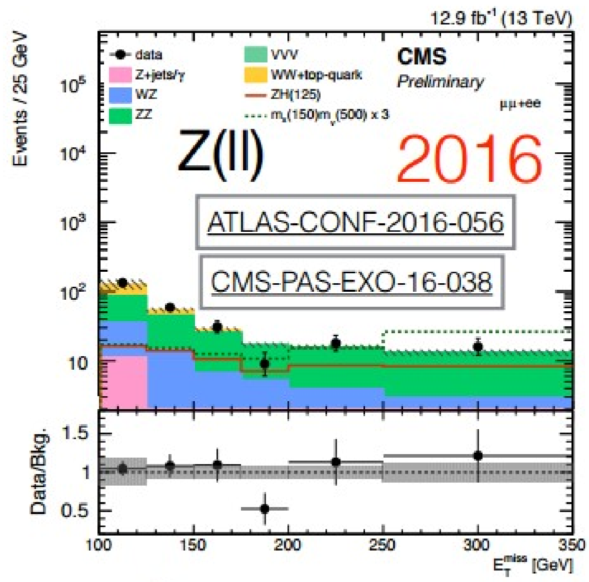
More mono-searches

$E_T^{miss}+\gamma$



ATLAS-CONF-2015-080

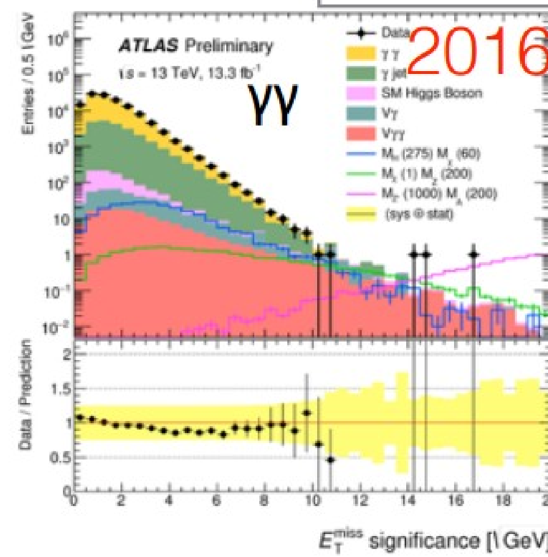
E_T^{miss} + W/Z



E_T^{miss}+H

CMS-PAS-EXO-16-011

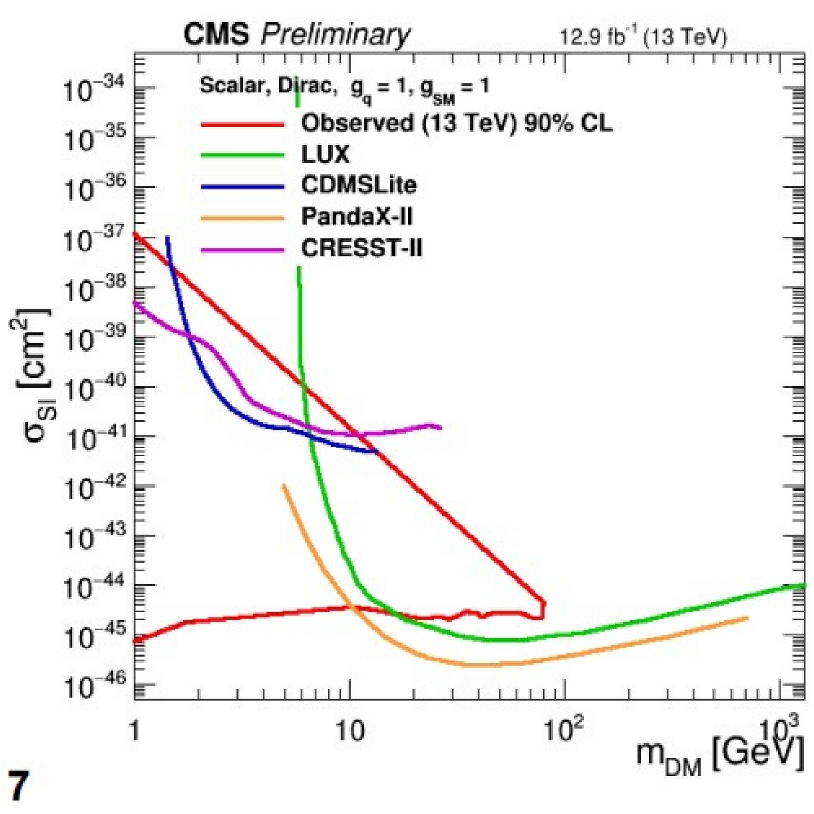
ATLAS-CONF-2016-087

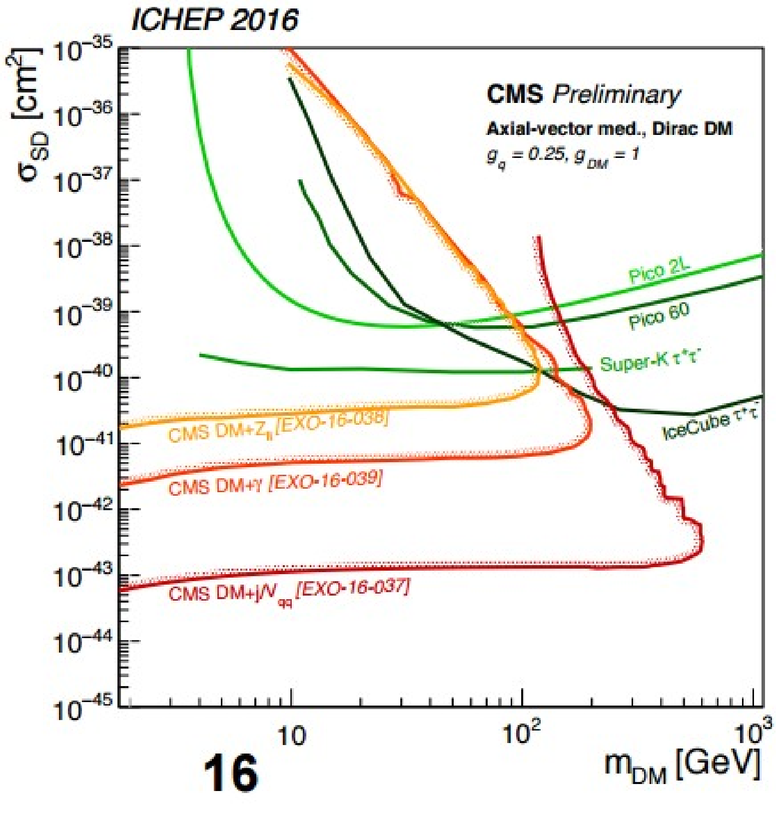


- Hadronically decaying bosons offer good sensitivity using sub-structure techniques, but not ready with 2016 data just yet.
- Everything looks in good agreement with backgrounds.

Dark matter interpretation

- Mono-X searches competitive with / complementary to direct detection searches, especially spin-dependent.





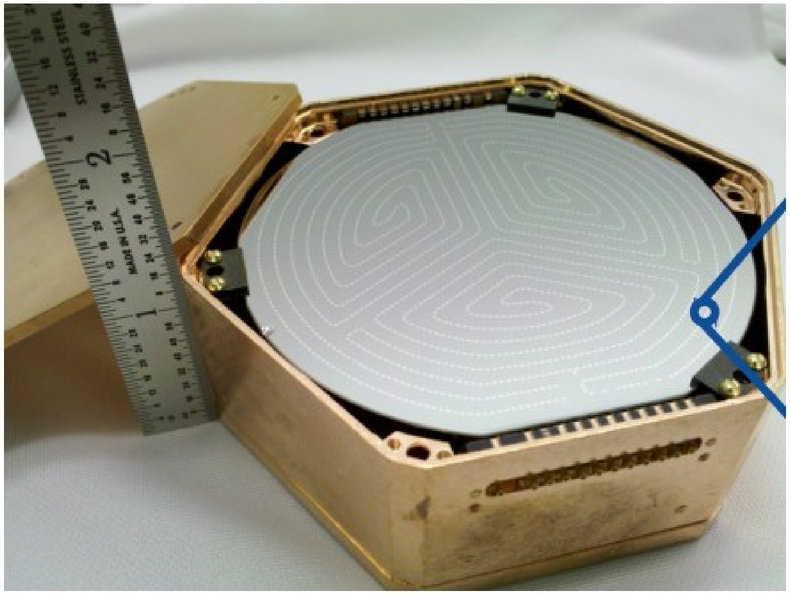
Dark Matter: Direct WIMP detection

LUX & LZ
XENON-100 & 1T
CRESST
PICO
XMASS
DEAP-3600 & beyond
NEWAGE
DMTPC
DAMA/NaI
DAMA/LIBRA
NEWS-SNO
SuperCDMS-Soudan
SuperCDMS-SNOLAB
DAMIC
CDEX
KIMS-NaI
PandaX-II
DarkSide-50 & 20k

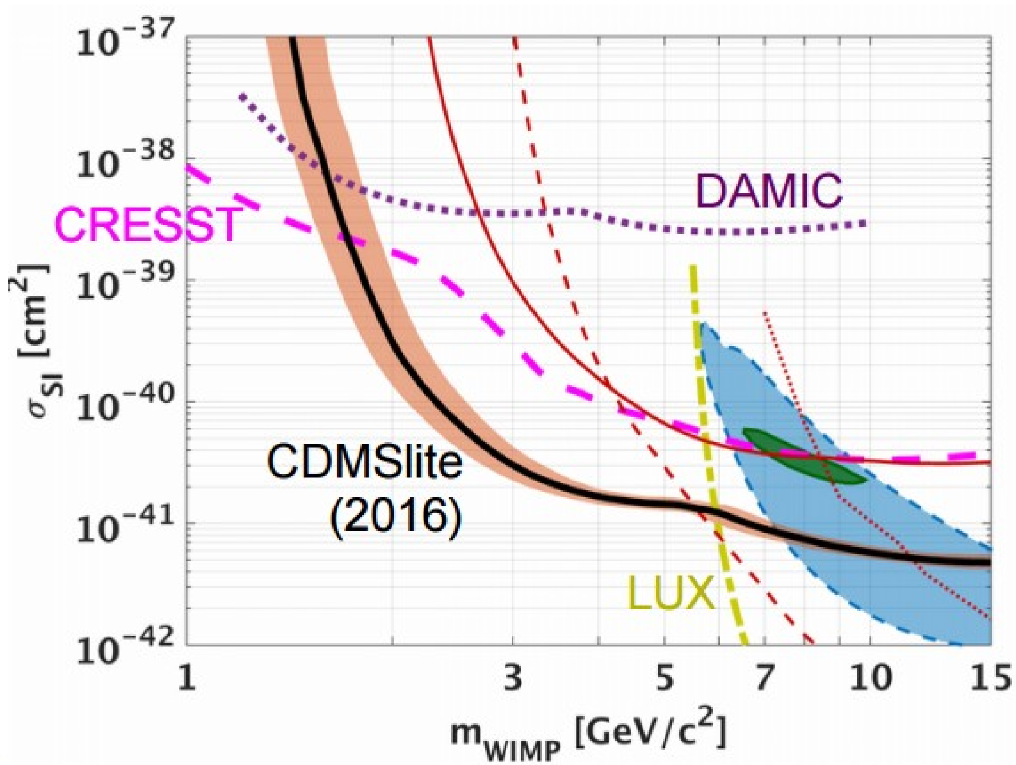
SABRE (N&S)
MiniCLEAN
Cogent
DRIFT
DARWIN
Edelweiss
DM-Ice
COSINE
KIMS
ANAIS
TREX-DM
NEWS

- Large number of experiments out there.
- We will carefully go through them one by one.

Low Mass: CDMSlite

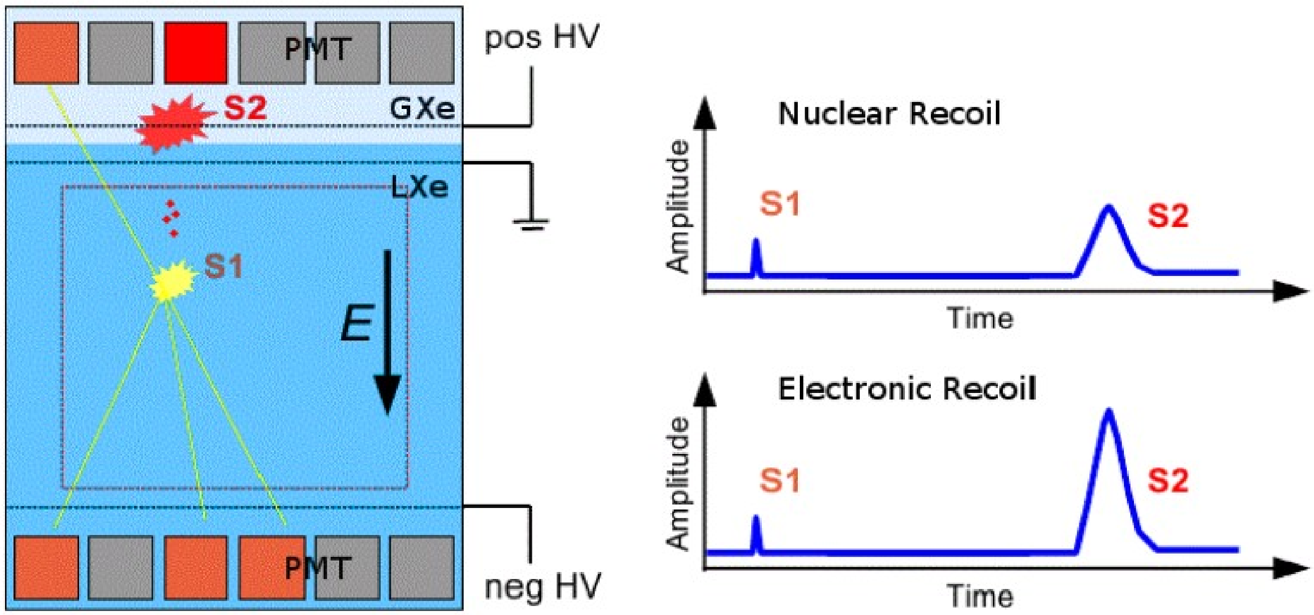


- 15 x 0.6 kg Germanium iZIP (interleaved Z-sensitive Ionization and Phonon) detectors in Soudan mine.



- Preparing next generation: 45 kg Si & Ge, located in SnoLab.
- Different operation modes & targets: sensitivity to variety of different (low) masses.

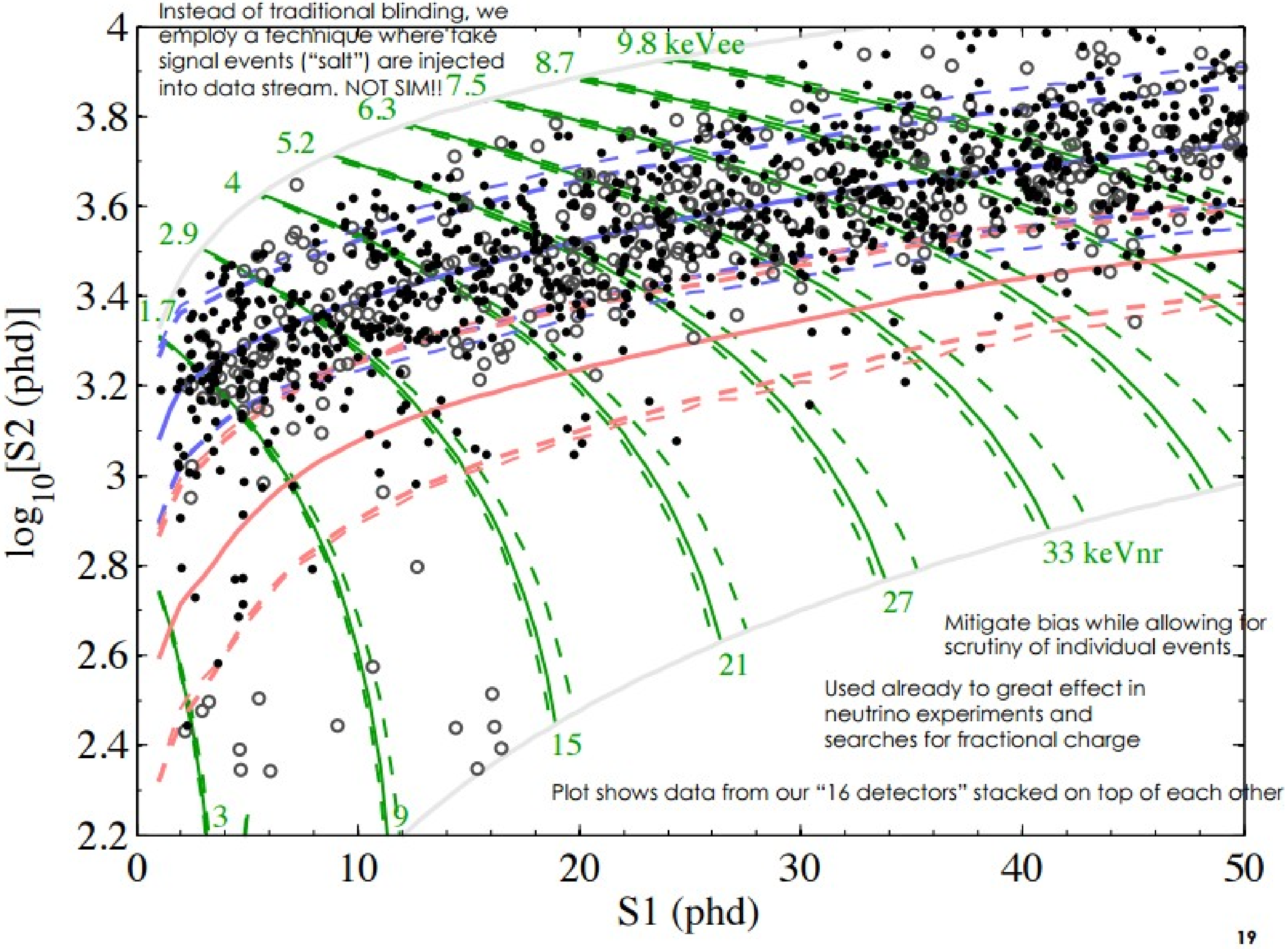
High mass: Large tubs of Xenon



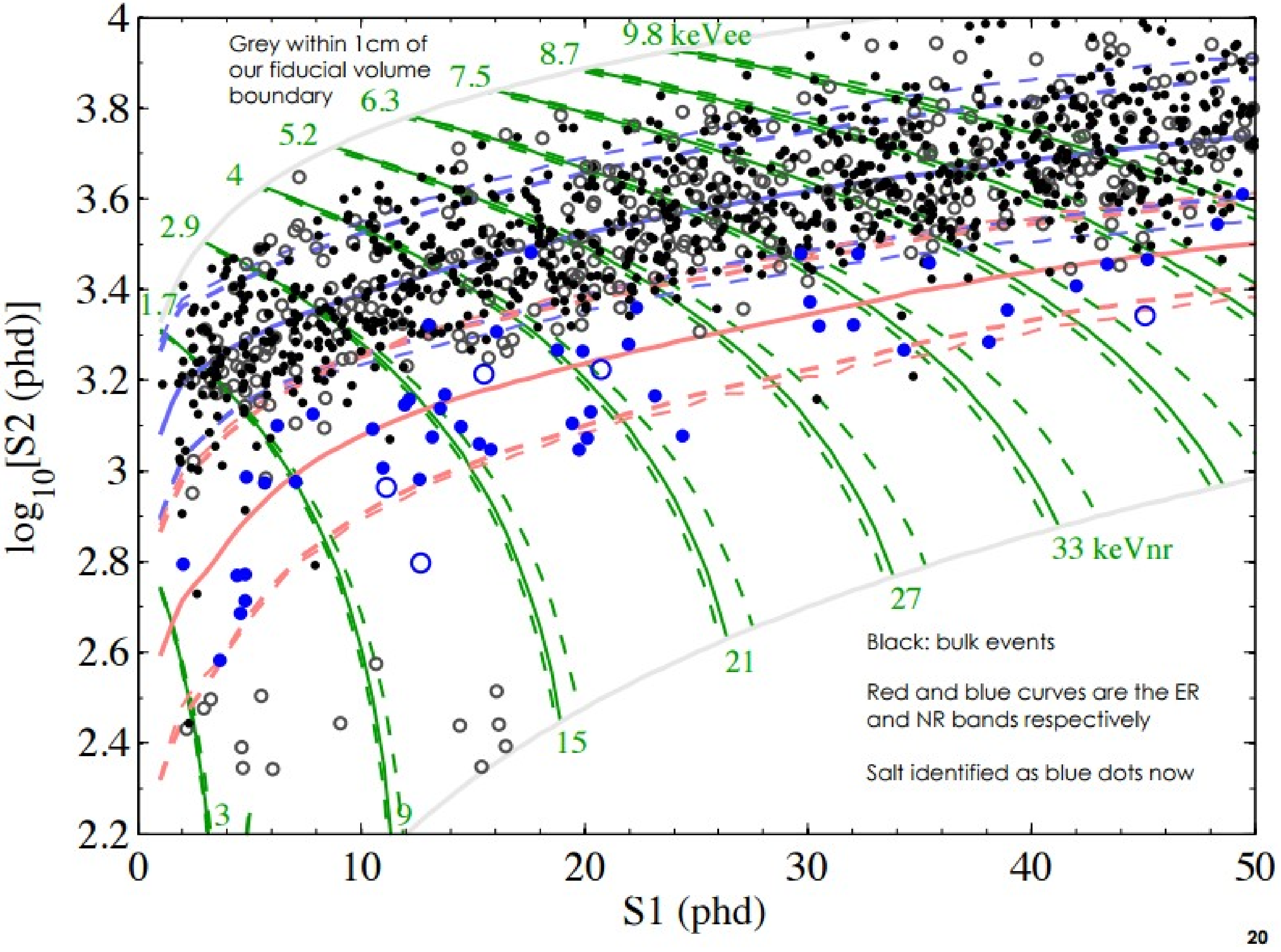
Scintillation light (S1) and ionization charge from primary event, which is converted to proportional scintillation (S2) in gas phase. Time between S1/S2 and top PMT pattern used to localize event. S2/S1 provides recoil discrimination.

relatively “new” application in DM, about 10 years

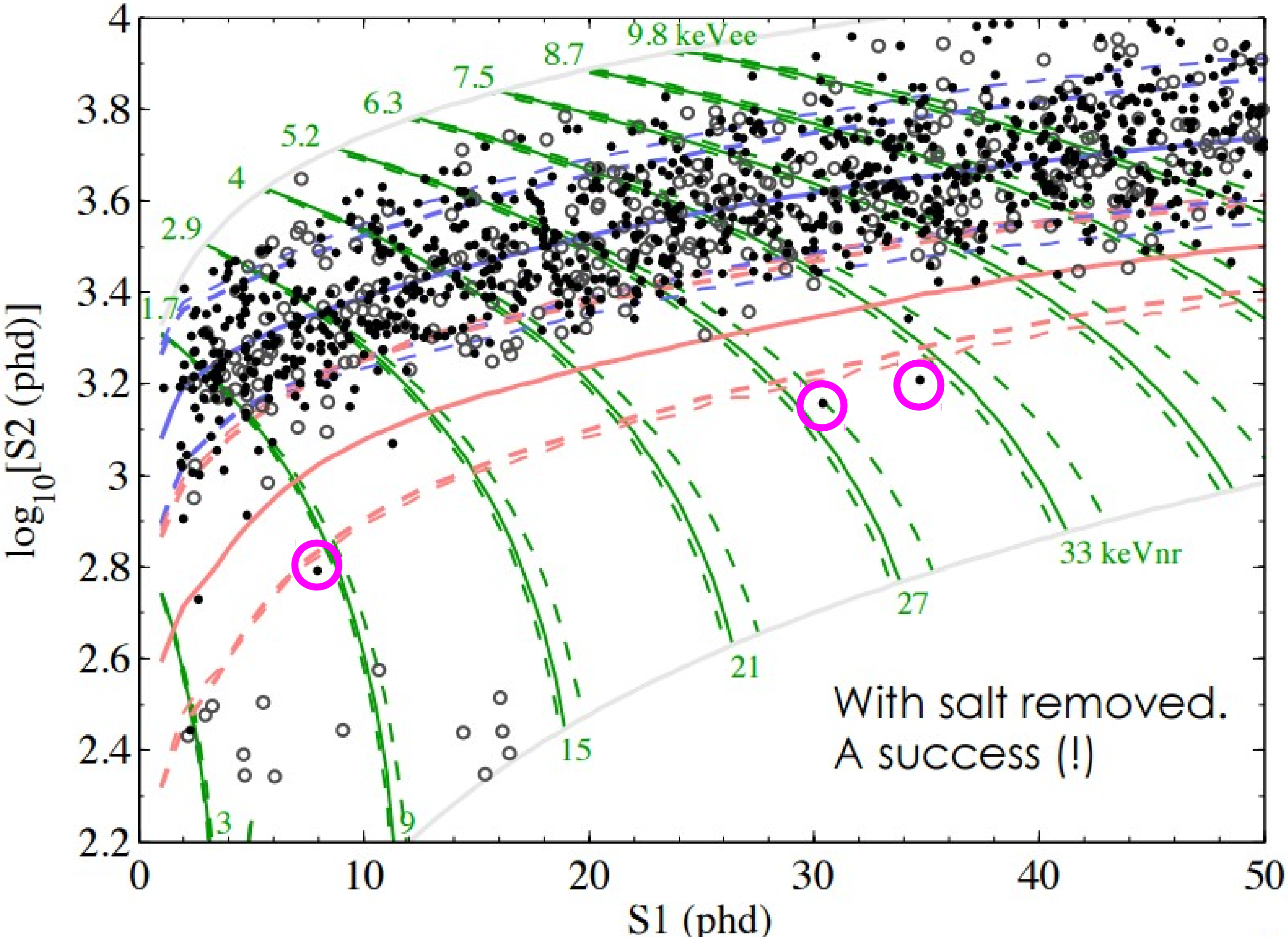
LUX: salted data



Lux: Unsalting



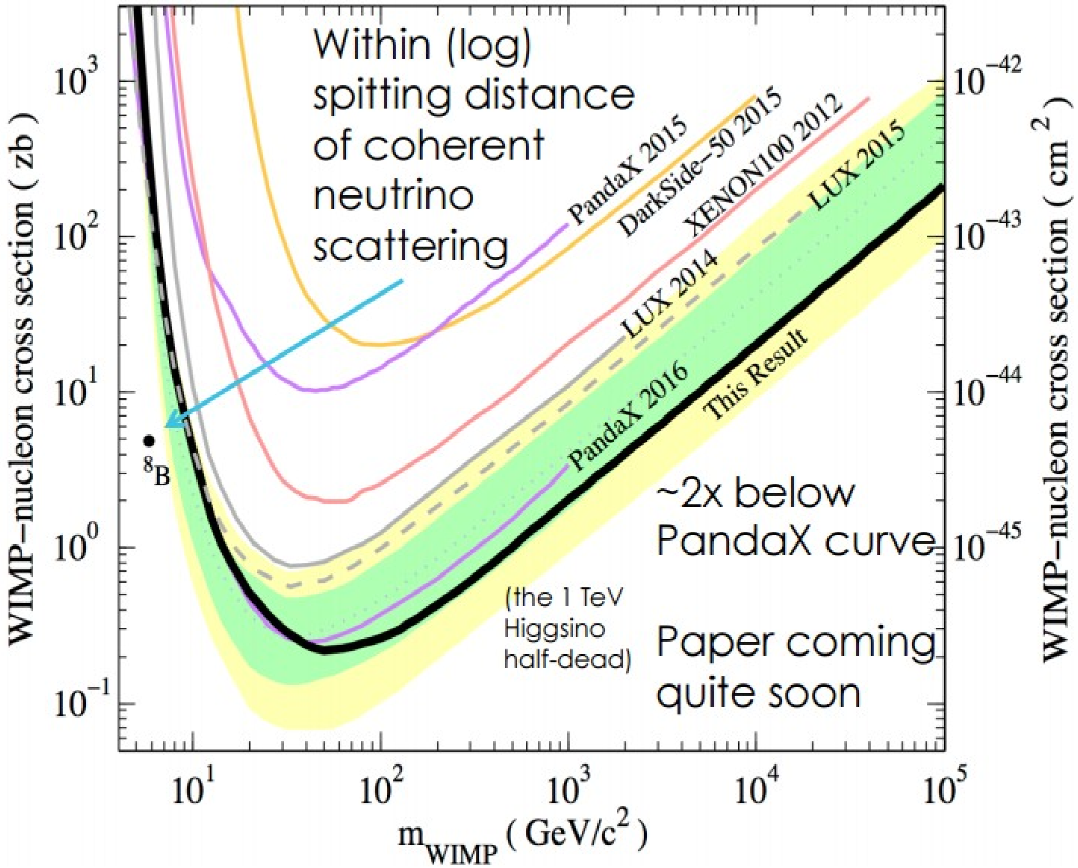
Lux: unsalted data



21

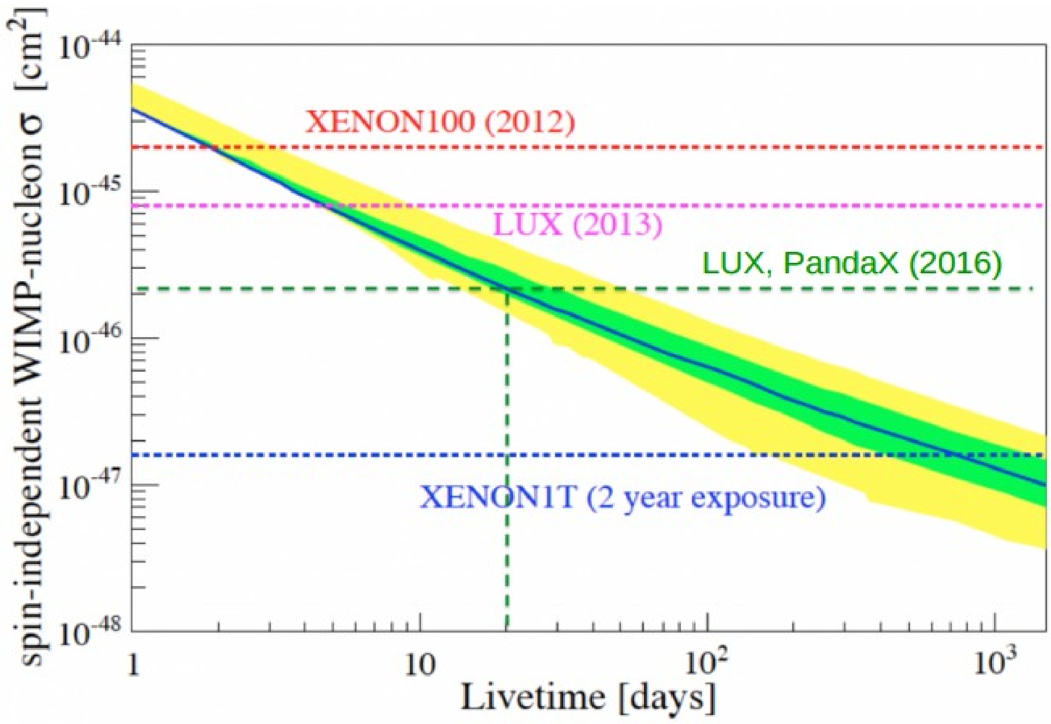
Three events below NR band observed. Closer inspection reveals they are not signal-like at all. Speaker: “We were so focused on our S2 quality cuts, we forgot to decide on any S1 cuts.”

High-mass: Current limits



- LUX is leading sensitivity (or tied with PandaX), but you may want to take their results with a grain of salt.
- People are seriously starting to discuss the “neutrino floor”.

Coming attractions: Xenon1T

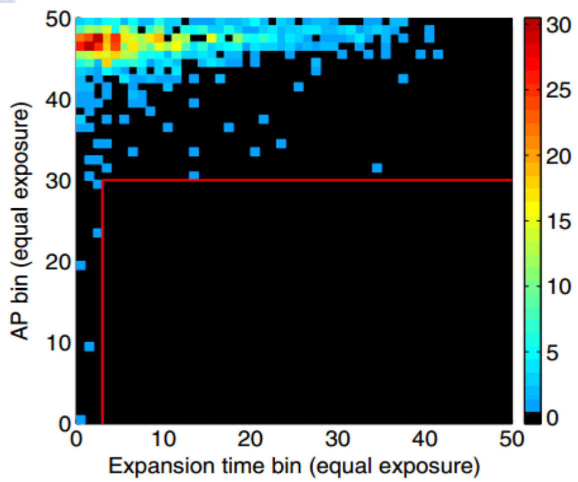


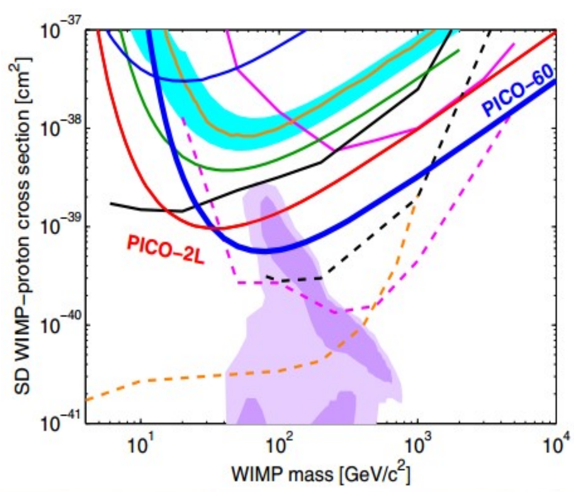
- Largest DM detector ever built!
- Filled with LXe since April 2016
- 248 PMTs
- 96 cm drift X 96 cm diameter
- High reflectivity teflon walls

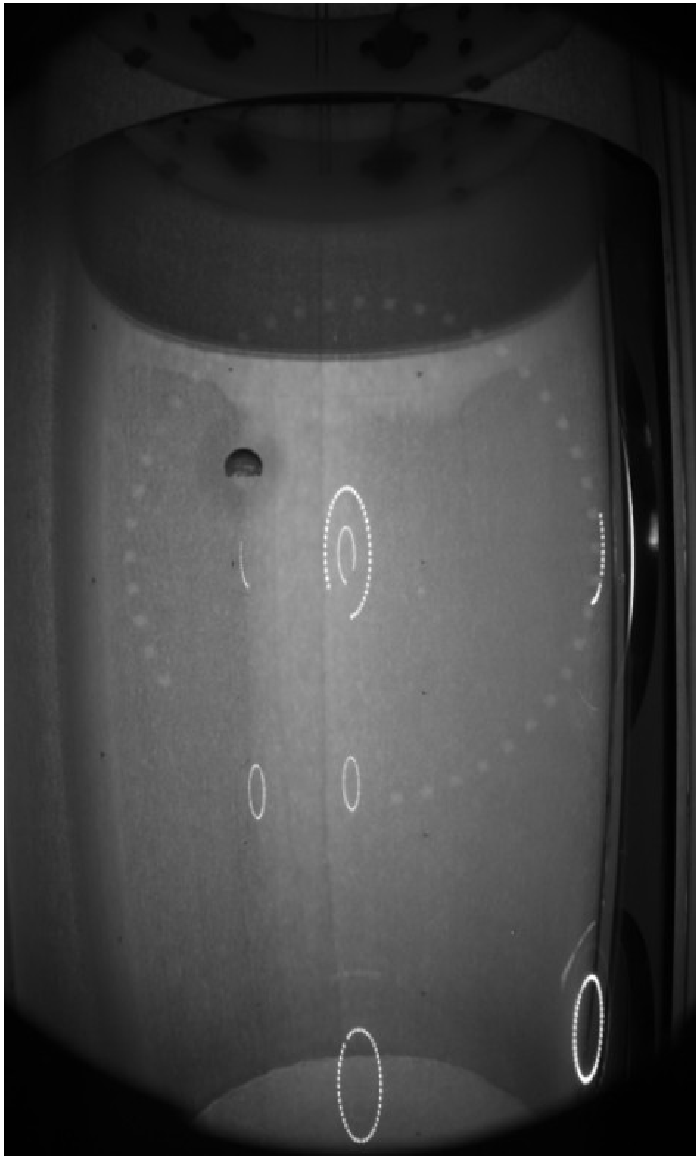
- Commissioning ongoing, run beginning soon.
- Need < 1 month to lead sensitivity.

Coming attractions: PICO

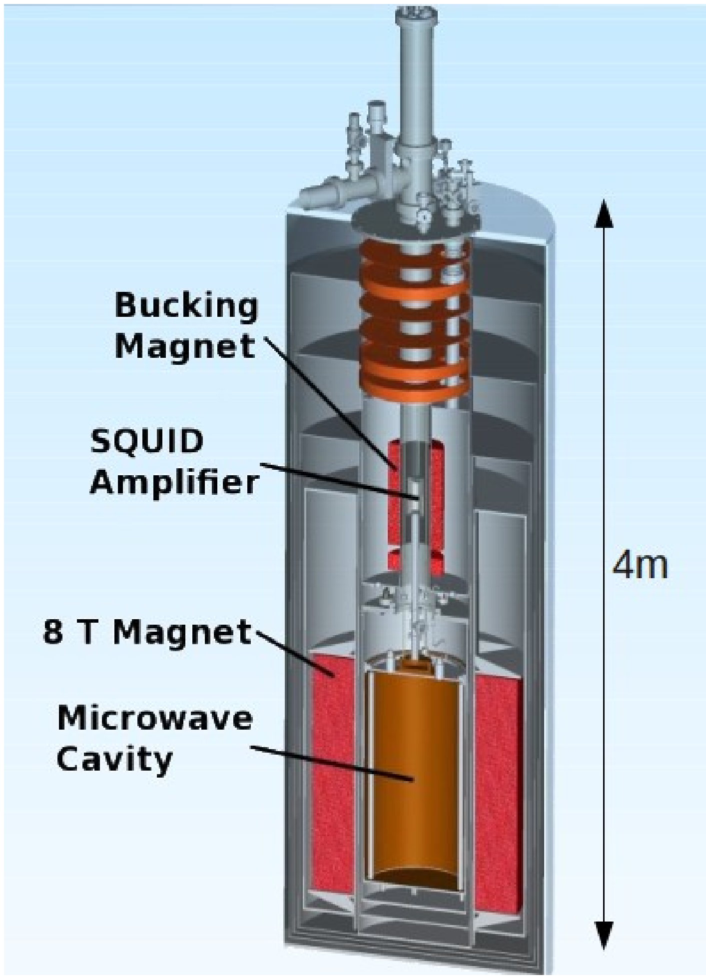
- PICO-60 1: World's largest bubble chamber, best limits on spin-dependent WIMPs after shadily tuning their cuts to avoid “anomalous background.”
- PICO-60 2: Same size but new liquid, figured out what that background was.
- Already observed “First Bubble”!! Results expected soon.



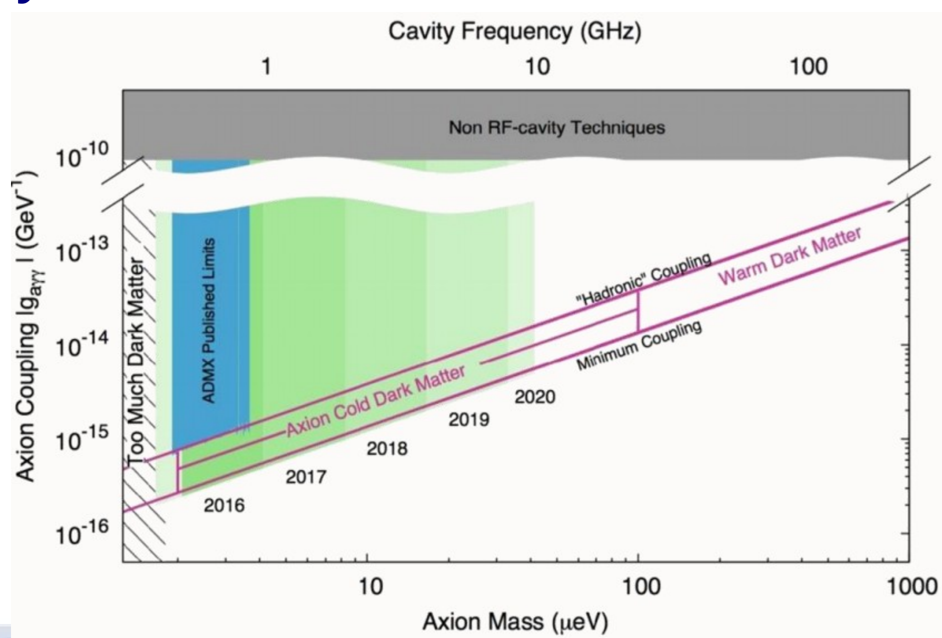




Coming attractions: ADMX



- RF cavity: most sensitive approach for finding dark matter axions or alps.
- Data taking has just begun!
- Possibility to exclude basically the whole parameter space in coming years.



Conclusions

- ICHEP 2016: The destroyer of dreams.
- I tried to play up small anomalies here and there but honestly I'm grasping at straws.
- Dark matter meanwhile could get very interesting in the coming months/years, if they stop changing their cuts every time some signal appears.