



# 38th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

AUGUST 3 - 10, 2016  
CHICAGO

Miriam Watson  
University of Birmingham



A few highlights, biased towards my interests

Slides mostly taken from plenary review talks  
(but there were no theory/experimental summaries)

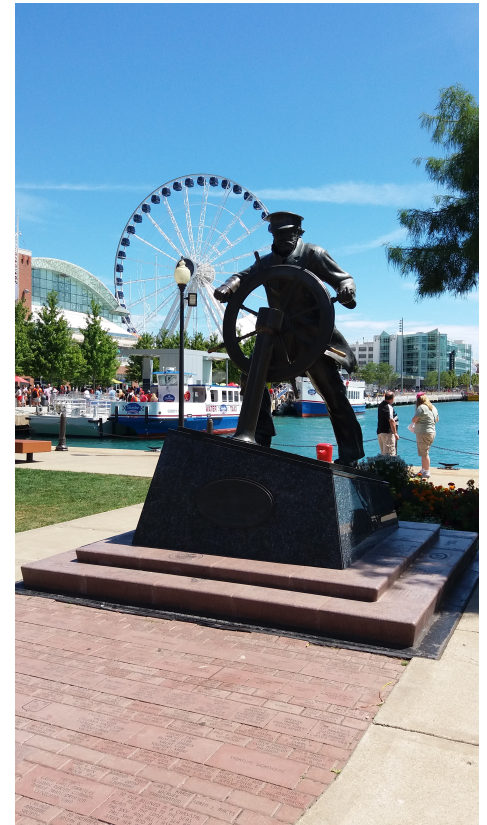


- Sheraton Grand Chicago
- 1,430 participants from 51 countries
- Organisation: slightly jet-lagged?

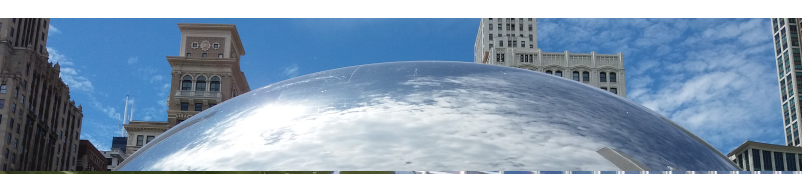




# The local area....









# Conference timetable

- 3 days each of parallel and plenary sessions
- A typical day of parallel sessions (09.00 – 19.00):

## Morning

Chicago IL USA		07:00 - 09:00																		
09:00	Exotic hadrons at the LHC (25' + 5')	Search for supersymmetry with jets...	The SID Detector for the Int...	CP asymmetries in SDs de...	Status of the CEPC Project, a...	Top quark production...	Atmosph Neutrino ...	Determin of the total LHC HL...	Precision Measurements	Inclusive searches for squar...	ATLAS Upgrades for the re...	Mixing at CP violati...	Recent BABAR r...	Beam Optics for FCC-ee C...	Theoret results for top-quar...	Solar neutrino r...	Measures of cross ...	Precision measurement		
10:00	Exotic hadrons at the Tevatr...	Search for supersymmetry in events ...	Detector Systems for the M...	Search for SCPS viol...	Research Latest development on the WbWb production...	Neutrino decay an...	Measures of Higgs ...	Exotic Rotational Correlations.	Inclusive searches for squarks and gluin...	Simulation for energy frontier (15' + 5')	CP Asymmetries in Many...	DDD9-ba mixing an...	The CER High Field Magnet P...	Measure of tbar-X using the...	Study of the disappearance with IceC...	Measures of cross ...	Sterile neutrino dark matt...			
11:00	Break	Outreach Training	Measurement of fermi...	What is delta alpha^2 (ae) ? (15' + 5')	Search for electroweak production	Design studies ...	Latest Results from the Pierre A...	Louis Henry	Fermila PIP-3 Status and Stra...	Higher-orders in heavy quark pr...	Search for the S...	Dr. Jigle Ling	Global Fits of the MSSM w...	David Hahn	Recent progress...	Results from the Telescop...	Charmi two-body...	Achieve Cen Zhang and future upgrade...		
12:00	First experience with the ...	The Geant4 Validation...	Linear Collider Software and Co...	Search for Higgs...	Spectral measurement of theta...	Phenon MSSM interpretat...	Perform study to...	Search for anis...	Recent Heavy F...	Update the HL-LHC ...	Top properties measurements...	Search for Higg...	First double-detector results f...	Check/Checkmat new physics ...	Dr. Achin Hoon	Upgrad of the A...	Detecti of High ...	CP violation in hadro...	Review Laser B...	Measur of top q...
13:00	Overview and Highlights of the B...	Combine results of the 125 ...	Theoretical motivations for the p...	Search for third generation	Design status a...	Search for third...	Dr. Yifeng Cao et al.	Dr. Yi Seon Jeon	Simulation of tau decay data (15' + 5')	Simulation of orientation	Measur of spin correlation...									
Lunch	Riverwalk A/B																			

## Afternoon

15:00	LHCb results w...	Data Acquisition with GPU...	Search for Sterile Ne...	Supersym versus Extra Dim...	The ATLAS Dataflow ...	IAXO, next-genera of heliosc...	VERITAS Observation of the Gal...	Anisotro flow and related p...	Will there be energy frontier c...	Zrjet production at NNLO (...)	Fermilab HEP Cloud: an elassic...	PROSPE A Short-b...	Si Xie Search fo...	The Fast Interaction...	CULTASK, the Coldest Axion Ex...	Multimes studies with the V...	Recent results on collective...	Moon storage for the Moon ...
16:00	Vrjets at MC modelling at the LHC (20' + 5')	The FIFE Project at Fermilab: Computing.	SoLid: Search fo...	Searches for SUSY in photons and tau c...	The CMS Level-1 Tr...	ADMX Status (30' + 10')	Measure of the Cosmic-ray Electron ...	Complan in small systems with ALIC...	Advance Controls for Particle Accelerators...	VINCIA Hadron Colliders ...	GeantV: from CPU to acceler...	Status of the MicroBooNE Experiment.	Naturaliz Supersymmetry with a Tw...	The Upgrade ...	Single Microwave Photon D...	Searches for Dark Matter an...	Measures of flow and correlation...	Reconist and Perspective...
17:00	Hadron spectroscop at BES-III ...	Results from the Search fo...	Lighting Collider Searches...	The Silo Vertex De...	Searching for Dark Matter Us...	Tools for Higgs Boson Pr...	Correlat new physics s...	Heavy Flavor Production...	Single To quark production...	Results from e+e- collisions...	Sterile Neutrino Searches...	Prospect for SUSY DM after t...	Silicon pixel RA...	Search for Dark Forces w...	Constrai on the Standard...	The Muo g-2 Experiment at Fermilab (20' + 5')	Quark and open heavy-Ba...	Single to quark production...
18:00	Production of exotic ...	The Shou Baseline Neutrino (SBN) Os...	Studies of dark sector at Belle & Bcays in...	The LHC VELO Up...	The Heavy Photon Search experiment...	SMEFT, theory for SM deviations...	Computi Hadronic Light by ...	What lattice QCD spectral functions...	Top physics at CLIC and ILC (15' + ...)	Charmon and botto...	Searching for a Sterile Neutrino ...	Lepton Jets from Radiating...	First testbeam ...	The PADME experiment...	Higgs productions in the glu...	Measure of hadron...	Transvers Momentum Distribution.	Top physics in pp colli...
19:00	Measure of the Col...	The TREK-E36 Search fo...	The front-end of IsoDA...	Role of low-energy observables	A High Resolution...	STAX: a new technique...	Charmon and bottomonium...	Lattice calculation of the HV...	3 Dimensional Stacked Pixel Detector and Sensor Technology Using less than 3-µm Robust Bump Junctions (12' + 3')	Makoto Motoyoshi et al.								

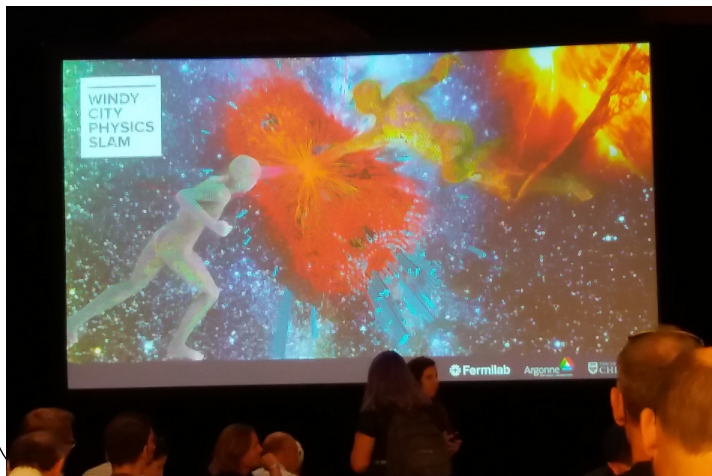
## Extra activities

- Outreach Training
- Conversation with Students at the African School for Fundamental Physics (2016, Rwanda)
- Lunch & Learn:
  - Engaging the public, how to make an impact
  - What makes a great physics news story, and the best way to tell it (BBC, Washington Post)
  - Making science fun and exciting through social media
- 1' Minute Elevator Speeches (x40)
- 2 poster sessions (different posters)
- Public lecture: Detection of Gravitational Waves from Binary Black Hole Mergers



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- Windy City Physics Slam

- ICHEP Zumba!



# LHC results: Standard Model and searches

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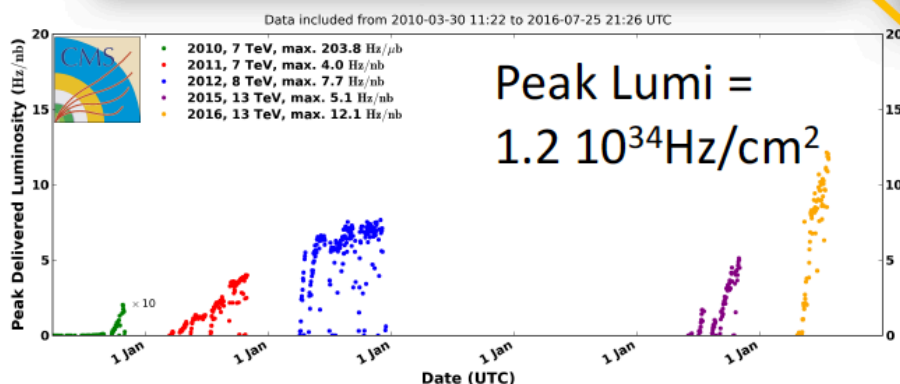
# LHC: a superb performance

- Thanks to the accelerator teams of CERN, the LHC has exceeded even the most optimistic performance estimates

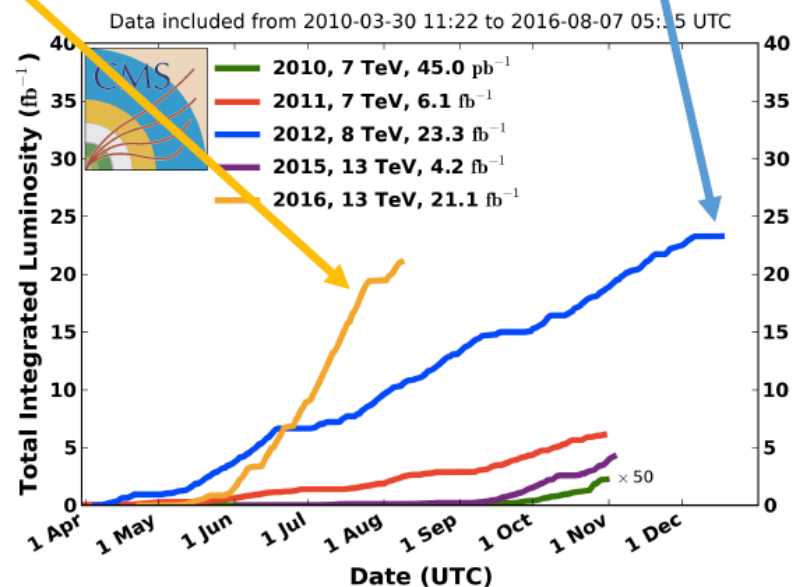
Luminosity used for the results presented today  $12.9 \text{ fb}^{-1}$

The estimate prior to the start of the 2016 campaign were to achieve something similar to the previous best ( 2012)

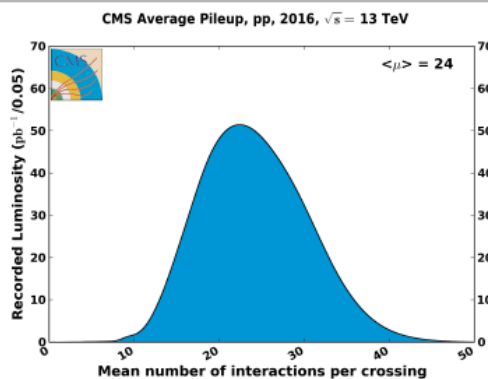
CMS Peak Luminosity Per Day, pp



CMS Integrated Luminosity, pp



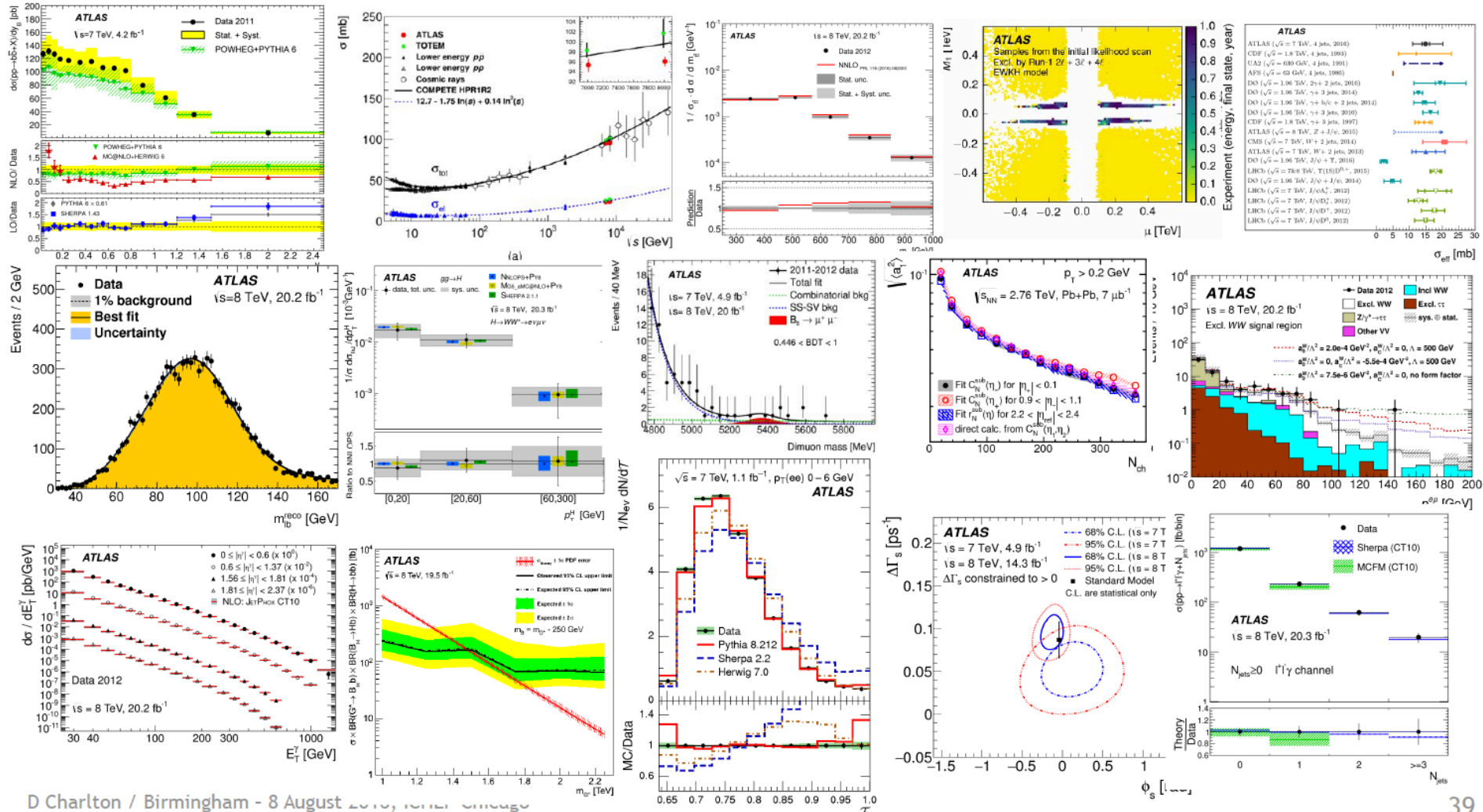
Pileup distribution for the data shown here



CMS livetime  $\sim 95\%$  and  $> 94\%$  of logged data usable for any physics analysis 4

# A Small Selection

In total **64** new results prepared for ICHEP, **56** using 13 TeV data and **45** with 2015+2016 ATLAS has now submitted **40** papers with Run-2 data (**576** total with collision data)  
The flood-tide of Run-1 results has not yet ebbed





# Search for a high mass diphoton resonance using the ATLAS detector

Bruno Lenzi (CERN)  
on behalf of the ATLAS collaboration

## Search for BSM physics in di-photon final states at CMS

C.Rovelli, INFN Roma  
On behalf of the CMS Collaboration

Pictures from CERN  
Twitter/Facebook



Parallel session talks

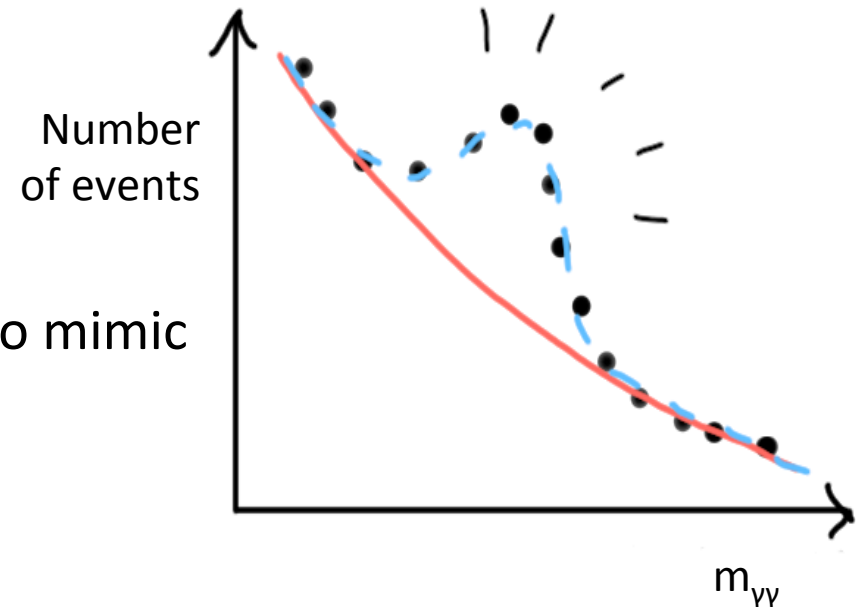
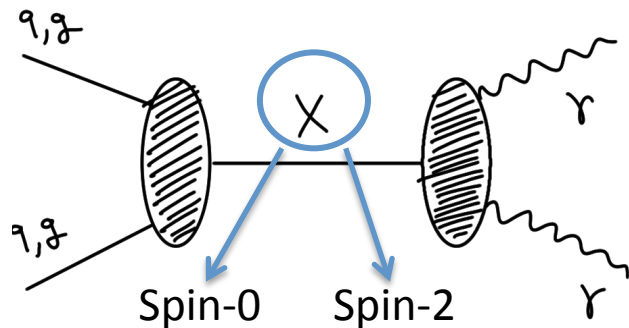


# Why di-photon searches

Fully reconstructed resonances: simplest way to discover new particles

Statistically significant peak  
over a smooth background

- experimentally robust
  - small systematics
  - difficult for unknown backgrounds to mimic
- ⇒ *simple yet striking signature!*



Final states with high  $p_T$  photons:

- relatively low background at hadron colliders
- good mass resolution

Many theoretical motivations

# Introduction

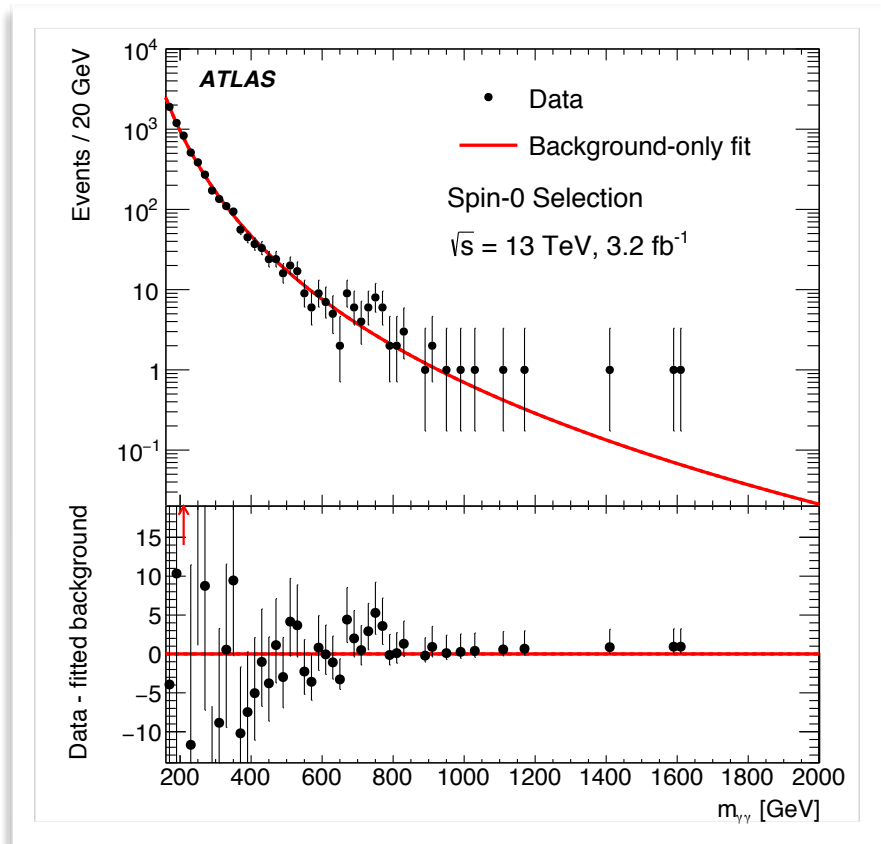
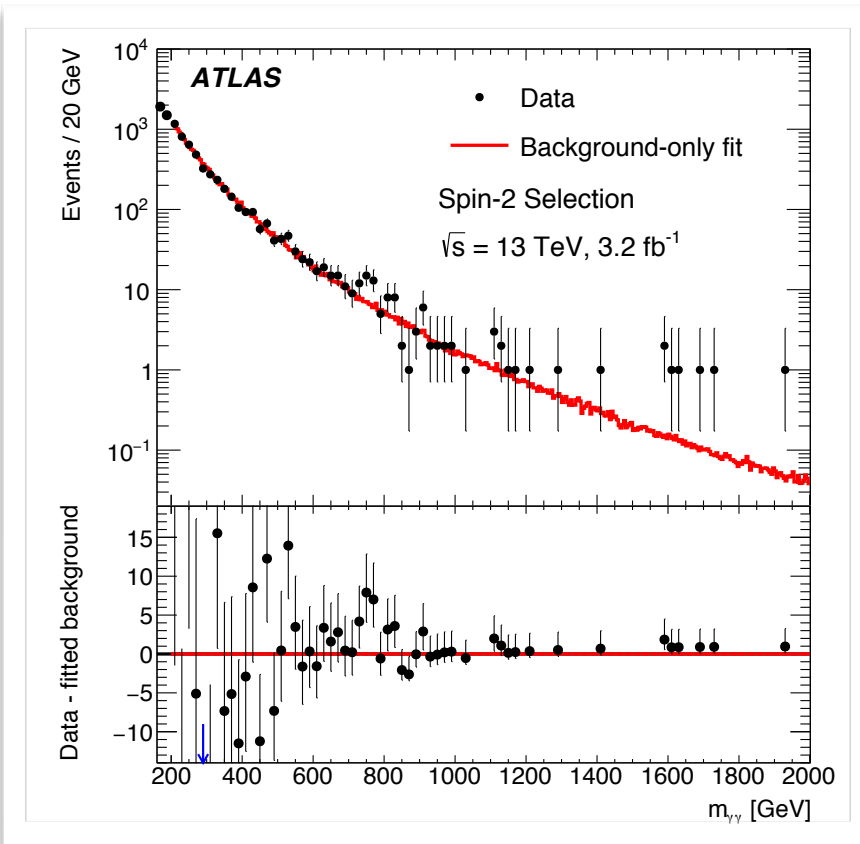
- Resonances decaying to diphotons predicted by several BSM models
- Search for peak (width  $\sim$  few %) over smoothly falling background

	Benchmark model	Search range (mass / additional parameter)	
Spin-2 (G)	RS graviton	500 GeV - 5 TeV	$k/M_{\text{pl}} = 0.01-0.3$
Spin-0 (X)	Higgs-like	200 GeV - 2.4 TeV	$\Gamma/m < 10\%$

- Results with 2015 data ( $3.2 \text{ fb}^{-1}$ ), submitted to JHEP ([arxiv:1606.03833](https://arxiv.org/abs/1606.03833))
- New results with  $15.4 \text{ fb}^{-1}$  of reprocessed 2015 data + 2016 data presented for the first time (ATLAS-CONF-2016-059)



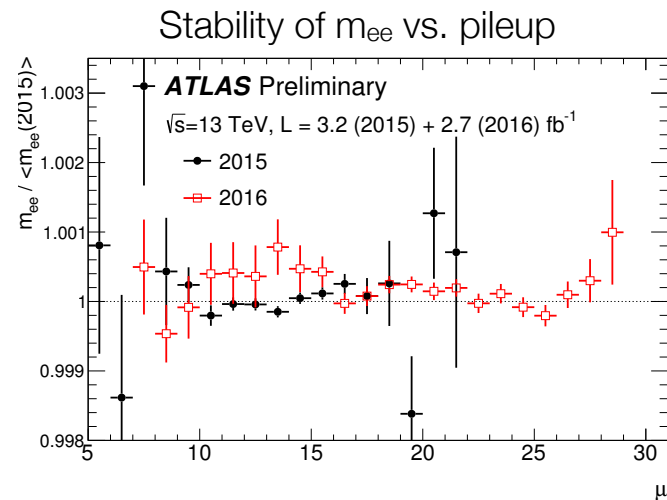
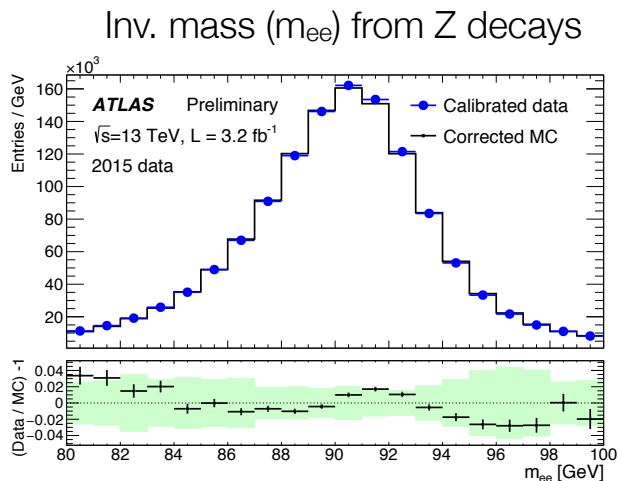
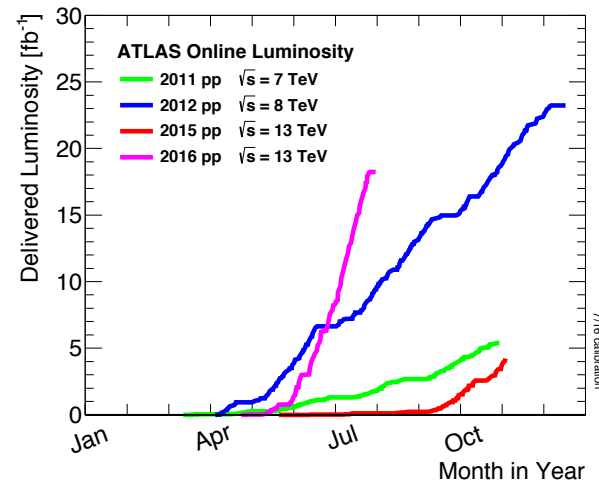
# Results from 2015 data (arxiv:1606.03833)



Broad excesses around  $m_{\gamma\gamma} = 750 \text{ GeV}$

# Since then...

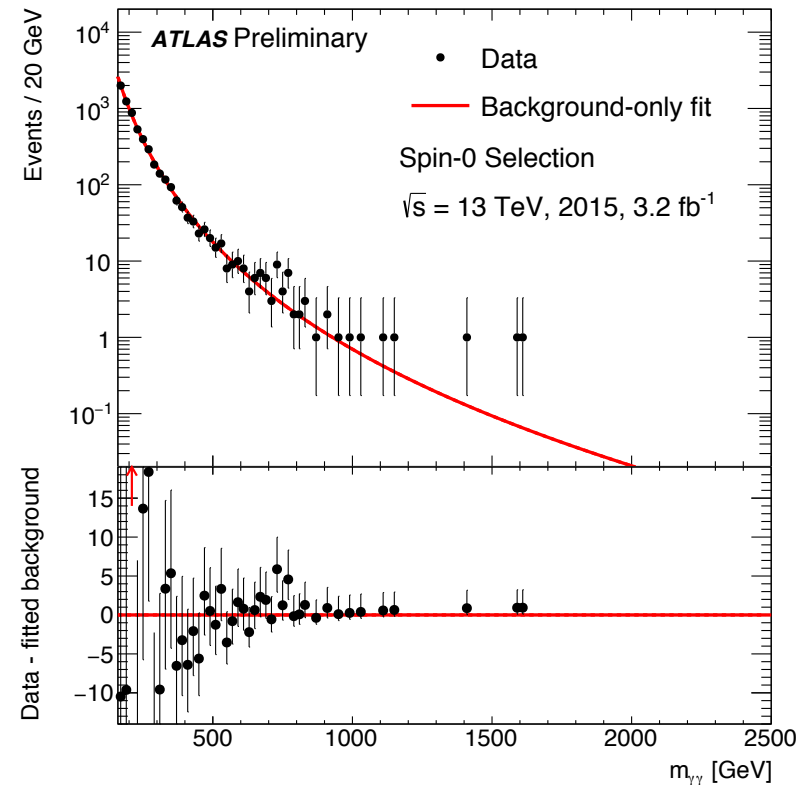
- Impressive performance of the LHC
  - Peak luminosity beyond design
  - ATLAS data-taking efficiency > 90%
  - 12.2 fb<sup>-1</sup> of 2016 data analysed
    - Data taken until July 16 (< 3 weeks ago!)
- Improved reconstruction and energy calibration, based on experience with 13 TeV data



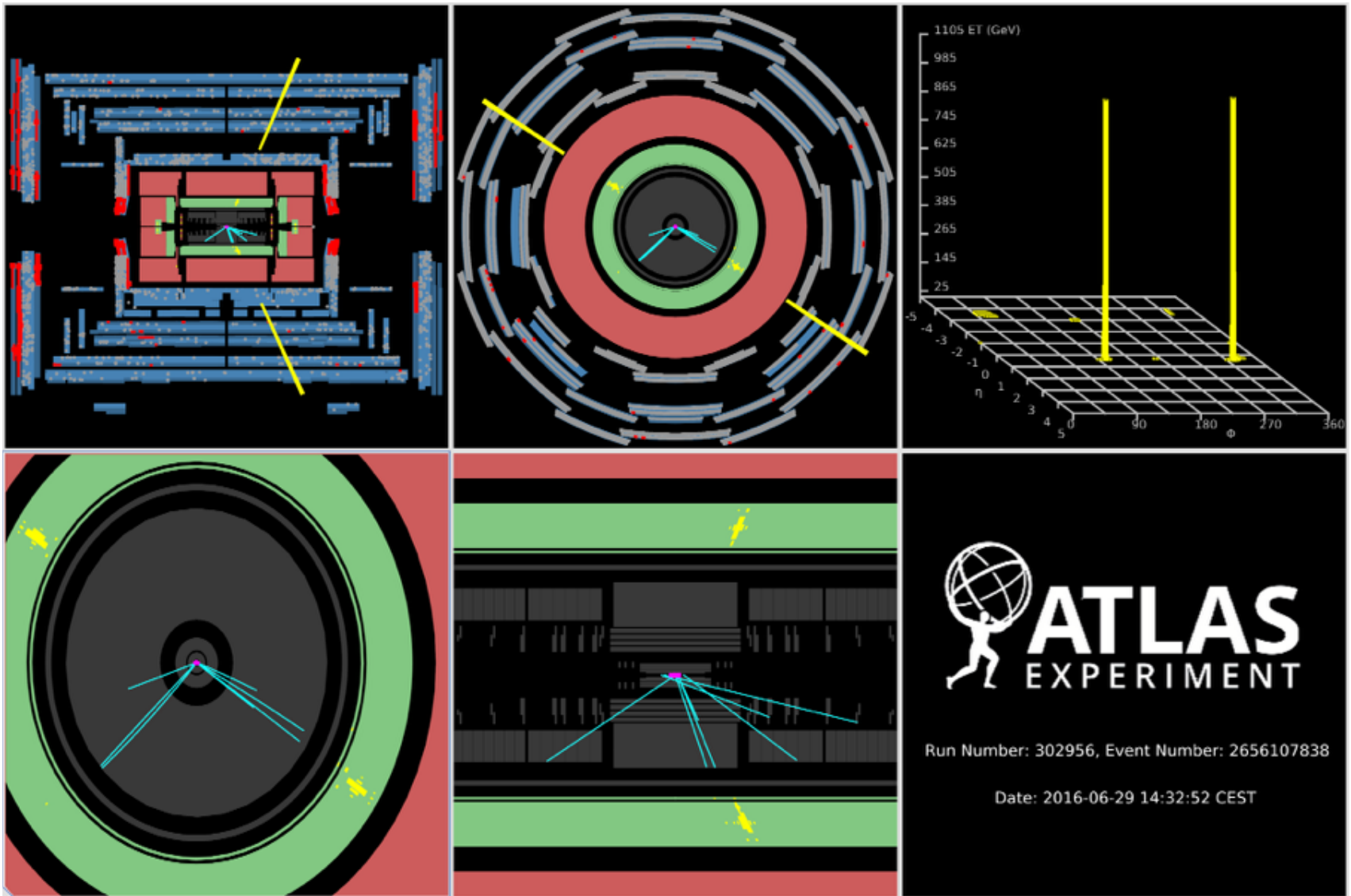
# The "new" 2015 data: spin-0 analysis

- 2015 reprocessed and reanalysed
- Excess @ 750 GeV  $\rightarrow$  730 GeV
- $3.9\sigma \rightarrow 3.4\sigma$  local significance
  - Basically 2 events affected by new reconstruction and calibration

With the higher pileup conditions of the 2016 data, more work is needed to complete the analysis in the extended acceptance of the spin-2 selection



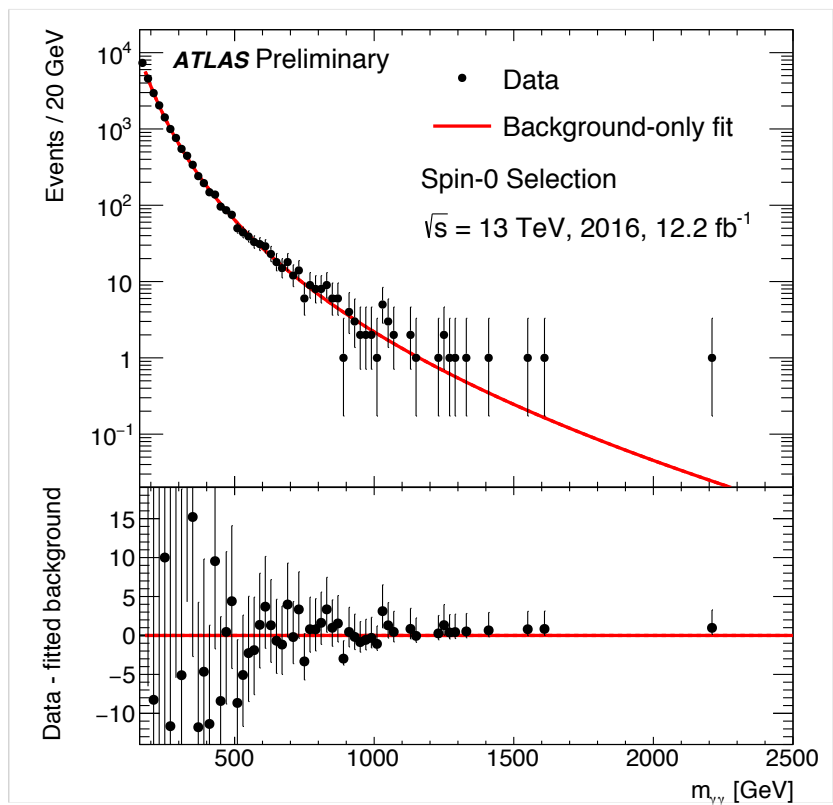
# A diphoton candidate with $m_{\gamma\gamma} = 2.2$ TeV



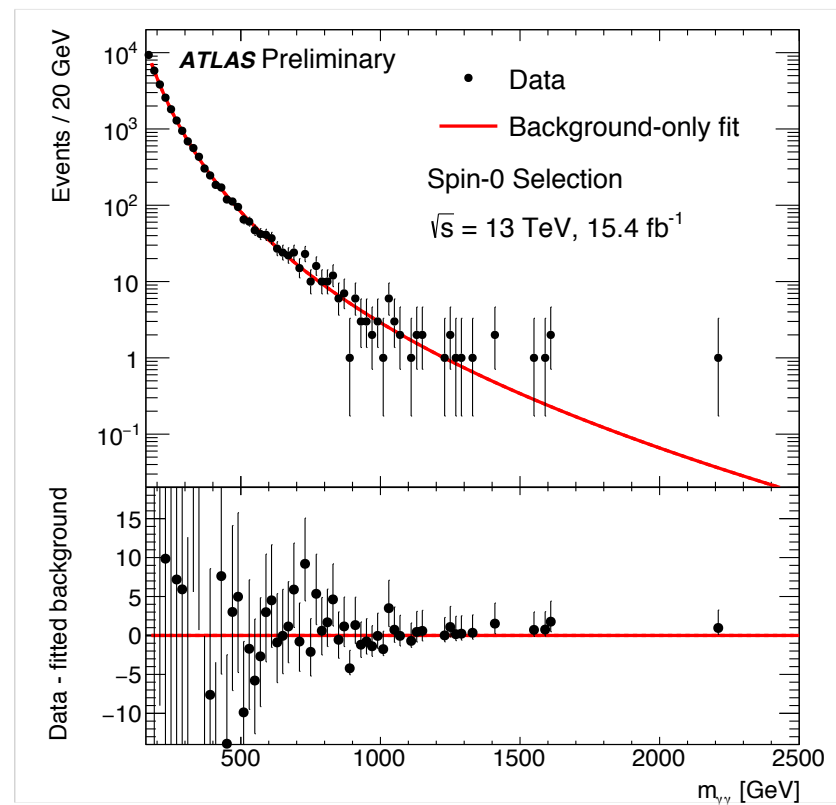


# Spectra for 2016-only and 2015 + 2016 data

2016-only



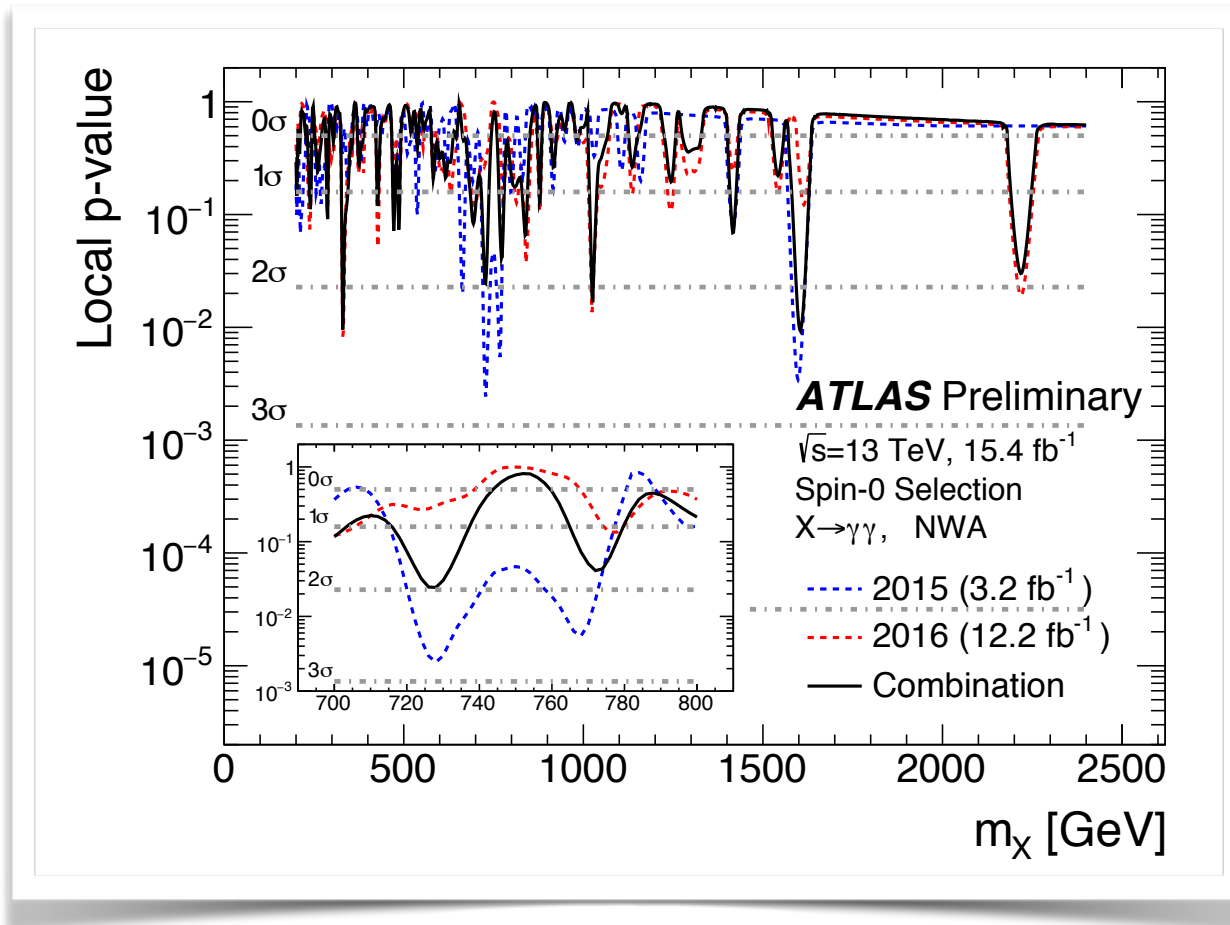
2015 + 2016



No significant excess in 2016 data, compatibility between 2015 and 2016 datasets for signal cross-section @ 730 GeV:  $2.7\sigma$

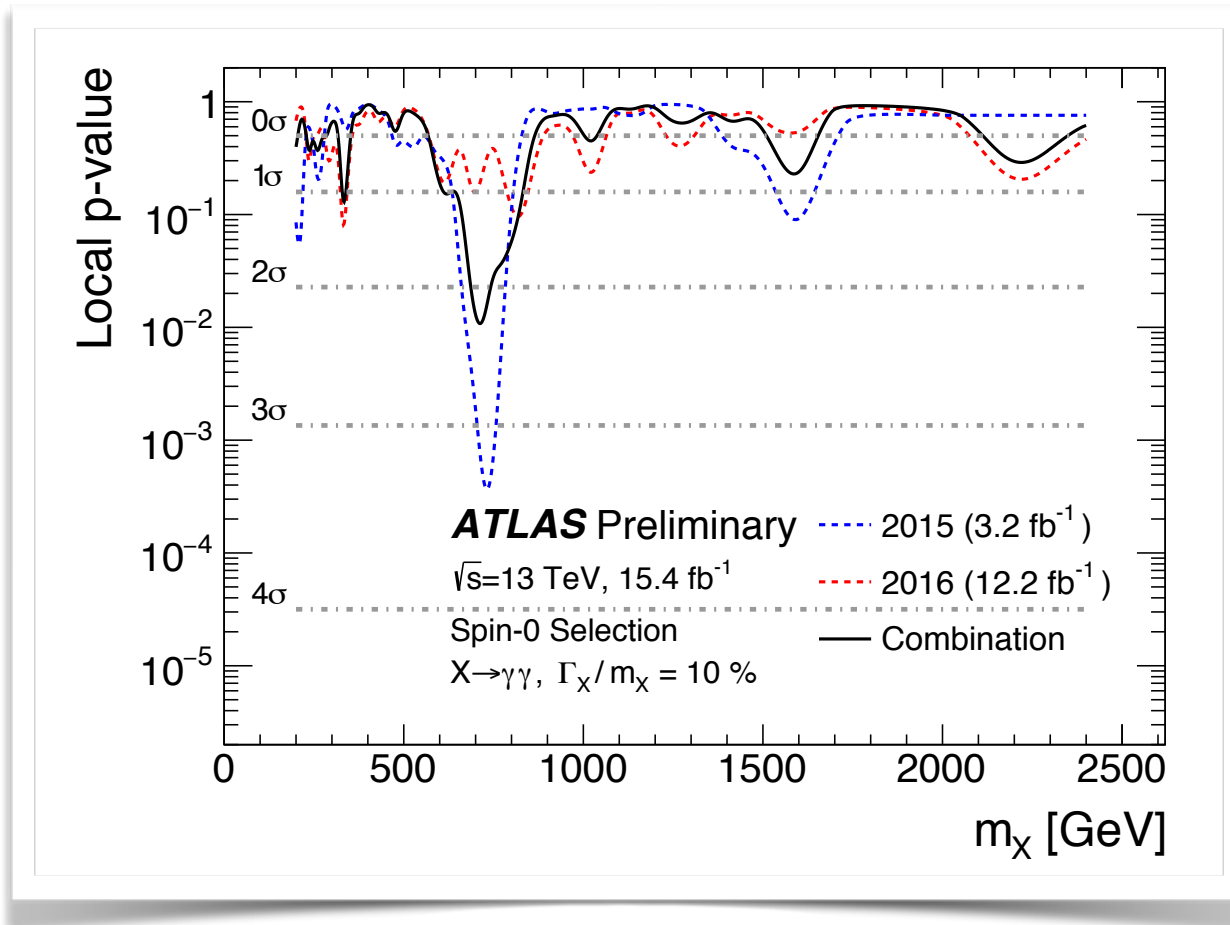
# New results: significances for narrow-width signal

Largest significance for combined dataset @ 1.6 TeV ( $2.4\sigma$  local)



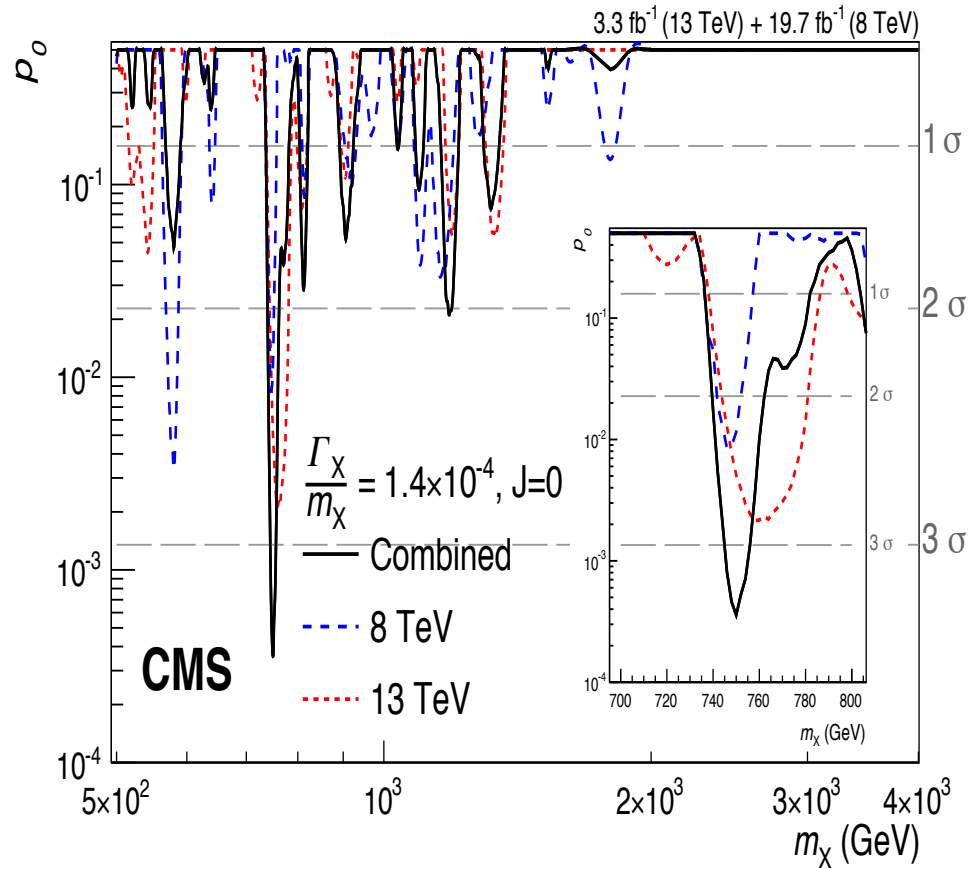
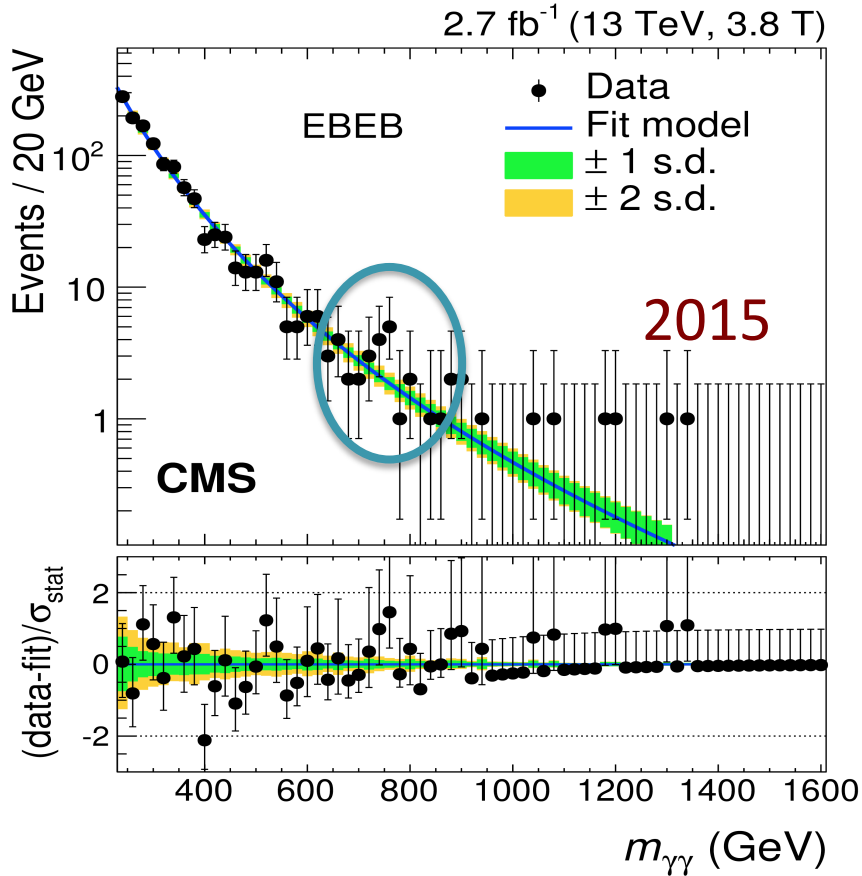
# New results: significances for wide signal (10%)

Around 700-800 GeV:  $2.3\sigma$  local significance @ 710 GeV for combined dataset



# Recap of 2015 results

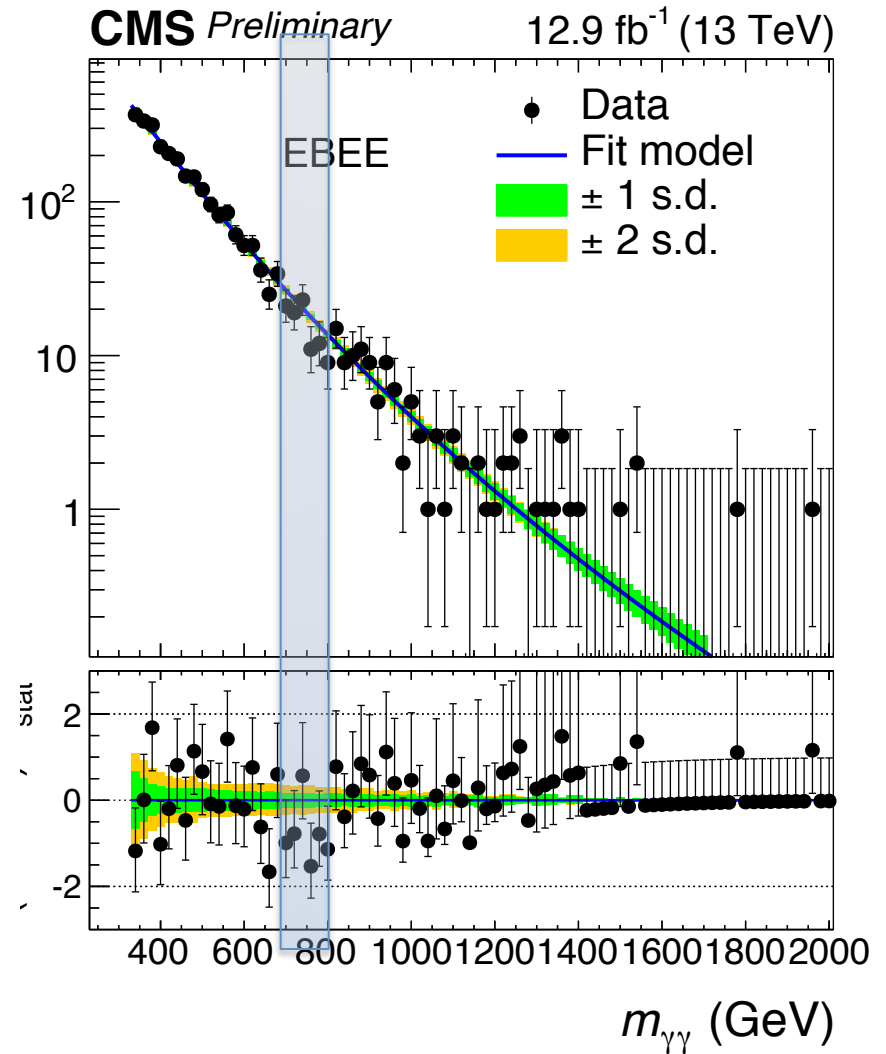
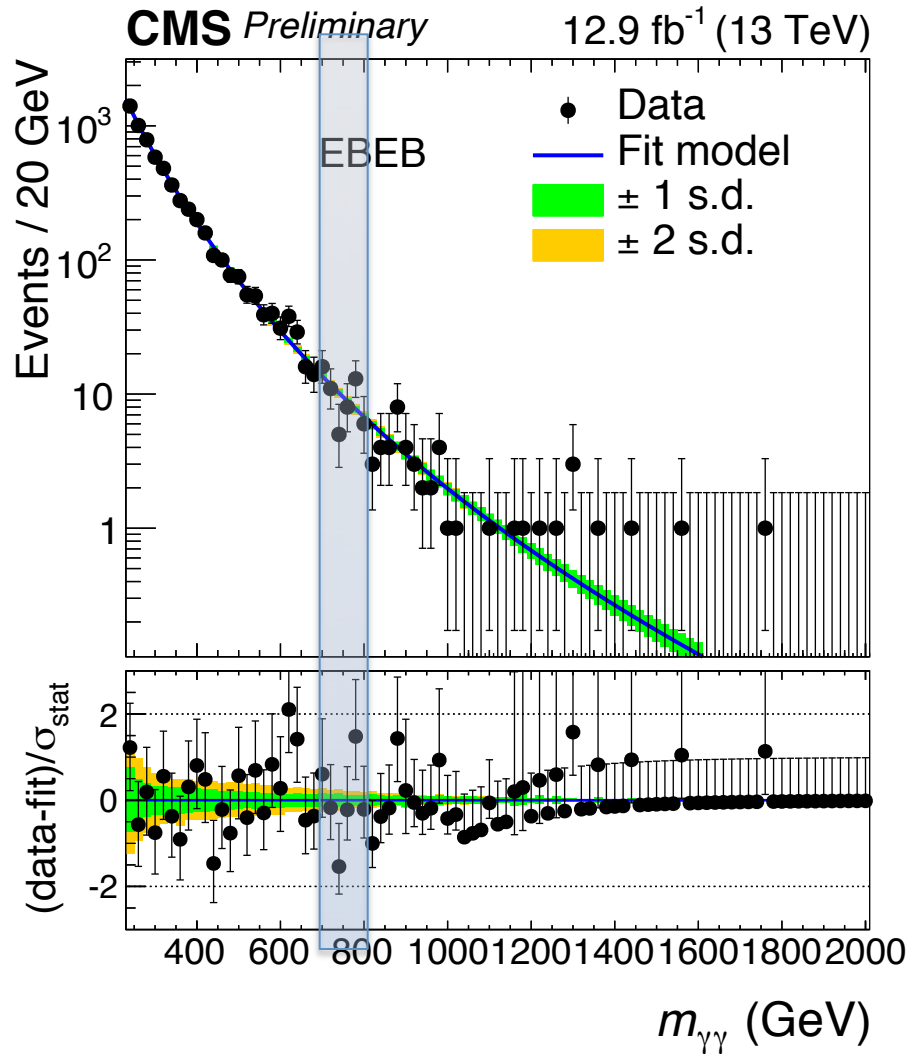
*Phys.Rev.Let. 117(2016), no. 5, 051802*



	2015	2015 + 8TeV
Mass (GeV)	760	750
Local significance	2.9σ	3.4σ
Global significance	<1σ	1.6σ

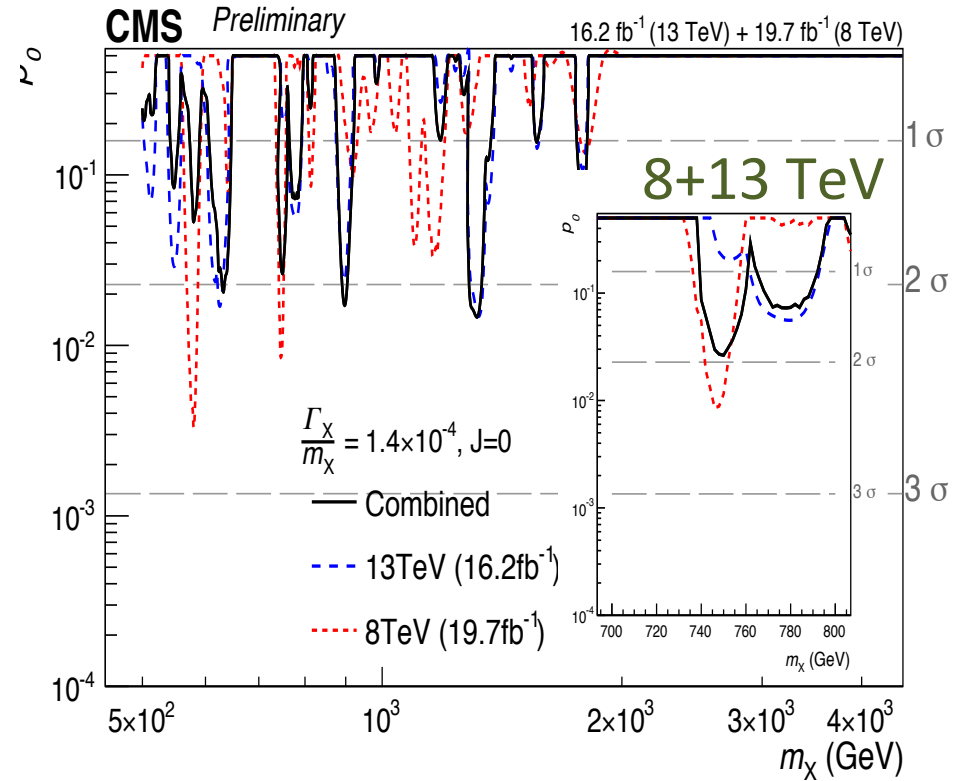
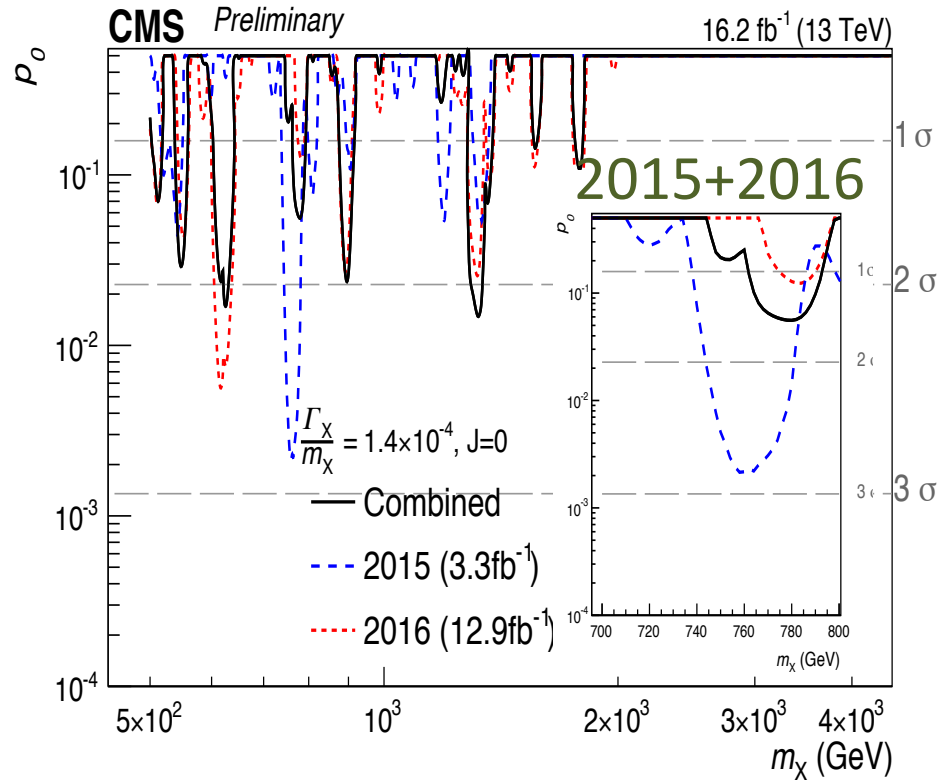


# 2016 mass spectra



Data consistent with Standard Model expectations

# Run1+Run2 significance



Spin-0,  $\Gamma_X/m_X = 1.4 \times 10^{-4}$  hypothesis

Local excesses around 750 GeV:

2015 only:  $2.9\sigma$   $\longrightarrow$  2015+2016:  $<1\sigma$

8TeV+2015:  $3.4\sigma$   $\longrightarrow$  8TeV+2015+2016:  $<2\sigma$

# Conclusions

## CMS

Data consistent with Standard Model expectations

Modest excess presented based on 2015 (+ 8TeV) data in the region around 750 GeV not confirmed by the new data

- Results at 750GeV compatible at level of  $2.4\sigma$

## ATLAS

- Spin-0 analysis updated with combined 2015 + 2016 dataset
  - Data consistent with background-only hypothesis over the full mass range
    - No excess with a global significance above  $1\sigma$
  - Broad excess around 750 GeV in 2015 data not seen in 2016 data for spin-0 analysis
- More work needed to complete the analysis in the extended acceptance of the spin-2 selection

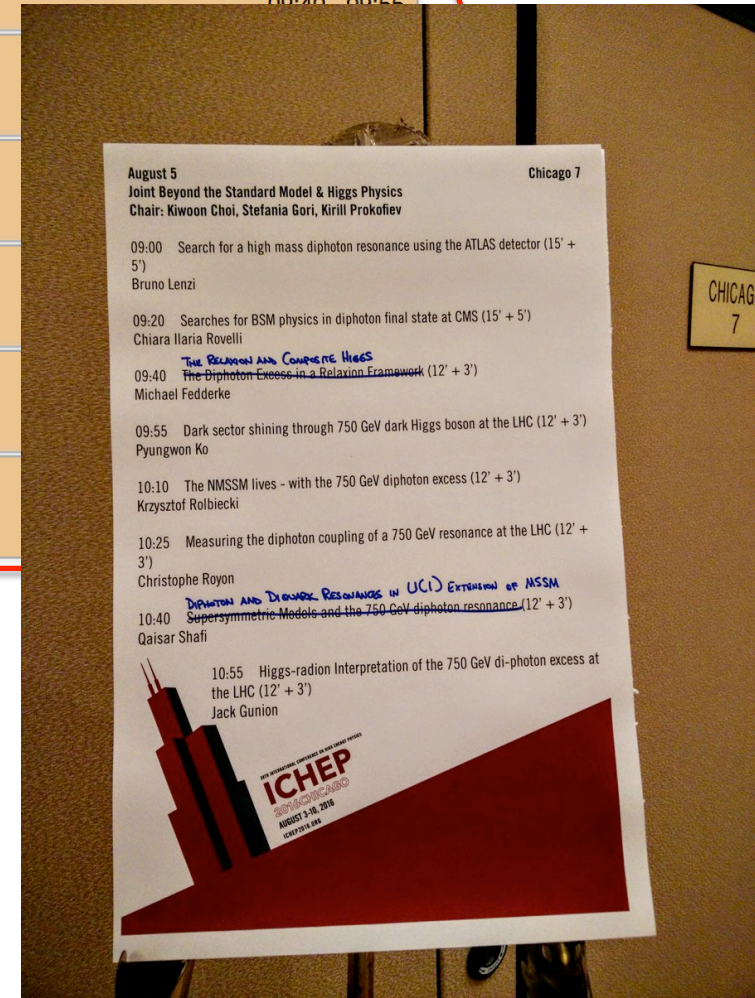
09:00	<b>Search for a high mass diphoton resonance using the ATLAS detector (15' + 5')</b> <i>Chicago 7</i>	<i>Bruno Lenzi</i>	09:00 - 09:20
	<b>Searches for BSM physics in diphoton final state at CMS (15' + 5')</b> <i>Chicago 7</i>	<i>Chiara Ilaria Rovelli</i>	09:20 - 09:40
	<b>The Relaxion and Composite Higgs (12' + 3')</b> <i>Chicago 7</i>	<i>Michael Fedderke et al.</i>	09:40 - 09:55
10:00	<b>Dark sector shining through 750 GeV dark Higgs boson at the LHC (12' + 3')</b> <i>Chicago 7</i>	<i>pyungwon ko et al.</i>	09:55 - 10:10
	<b>The NMSSM lives - with the 750 GeV diphoton excess (12' + 3')</b> <i>Chicago 7</i>	<i>Krzysztof Rolbiecki et al.</i>	10:10 - 10:25
	<b>Measuring the diphoton coupling of a 750 GeV resonance at the LHC (12' + 3')</b> <i>Chicago 7</i>	<i>Christophe Royon et al.</i>	10:25 - 10:40
	<b>Diphoton and Diquark Resonances in U(1) Extension of MSSM (12' + 3')</b> <i>Chicago 7</i>	<i>qaisar shafi</i>	10:40 - 10:55
11:00	<b>Higgs-radion Interpretation of the 750 GeV di-photon excess at the LHC (12' + 3')</b> <i>Chicago 7</i>	<i>Jack Gunion</i>	10:55 - 11:10



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Some hasty editing....

The NMSSM lives  
(with or without a diphoton excess)



or not ....

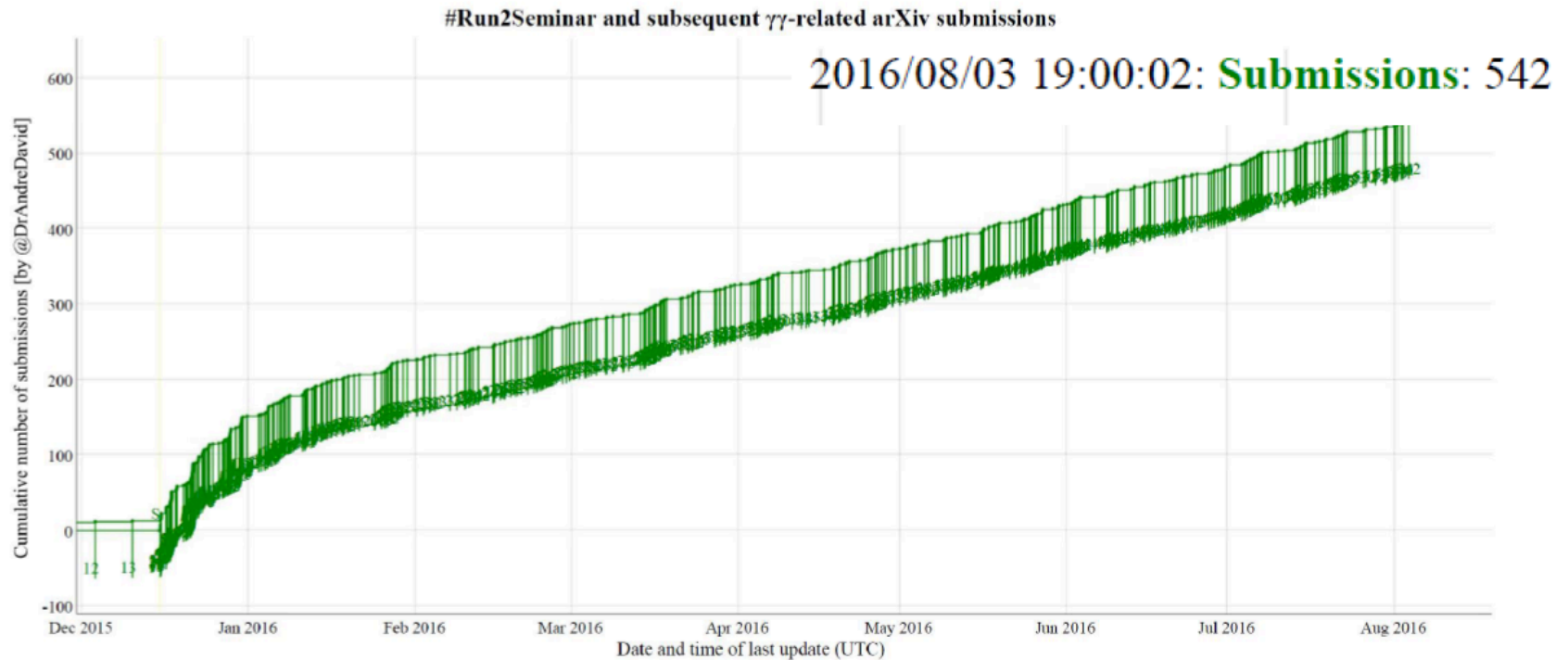
# My own related works

- [arXiv:1512.07853](#), “A Higgcision study on the 750 GeV Di-photon Resonance and 125 GeV SM Higgs boson with the Higgs–Singlet Mixing”, with [Kingman Cheung](#), [Jae Sik Lee](#), [Po-Yan Tseng](#), (and work in progress)
- [arXiv:1601.00586](#), “Diphoton Excess at 750 GeV in leptophobic U(1) model inspired by E6 GUT”, with [Yuji Omura](#), [Chaehyun Yu](#)
- [arXiv:1601.02490](#), “Dark sector shining through 750 GeV dark Higgs boson at the LHC”, with [Takaaki Nomura](#)
- [arXiv:1602.07214](#), “Confronting a New Three-loop Seesaw Model with the 750 GeV Diphoton Excess”, with [Takaaki Nomura](#), [Hiroshi Okada](#), [Yuta Orikasa](#)
- [arXiv:1602.08816](#), “ADMonium: Asymmetric Dark Matter Bound State”, with [Xiao-Jun Bi](#), [Zhaofeng Kang](#), [Jinmian Li](#), [Tianjun Li](#)
- [arXiv:1603.08802](#), “750 GeV diphoton excess as a composite (pseudo)scalar boson from new strong interaction” with [Chaehyun Yu](#) and [T.C. Yuan](#), [composite models](#)

• 750 GeV excess = dark Higgs

What have we learned?

**750 GeV flood!** <https://jsfiddle.net/adavid/bk2tmc2m/show/>



Theorists have been so hungry for experimental discovery, a lot more than what we have thought.

## **This was not an waste of time!**

We could learn more on many things related to BSM physics which communicate with the SM mainly through the SM gauge bosons:

Vector-like fermions,

EW symmetry preserving new strong forces,

Axion-like-particles,

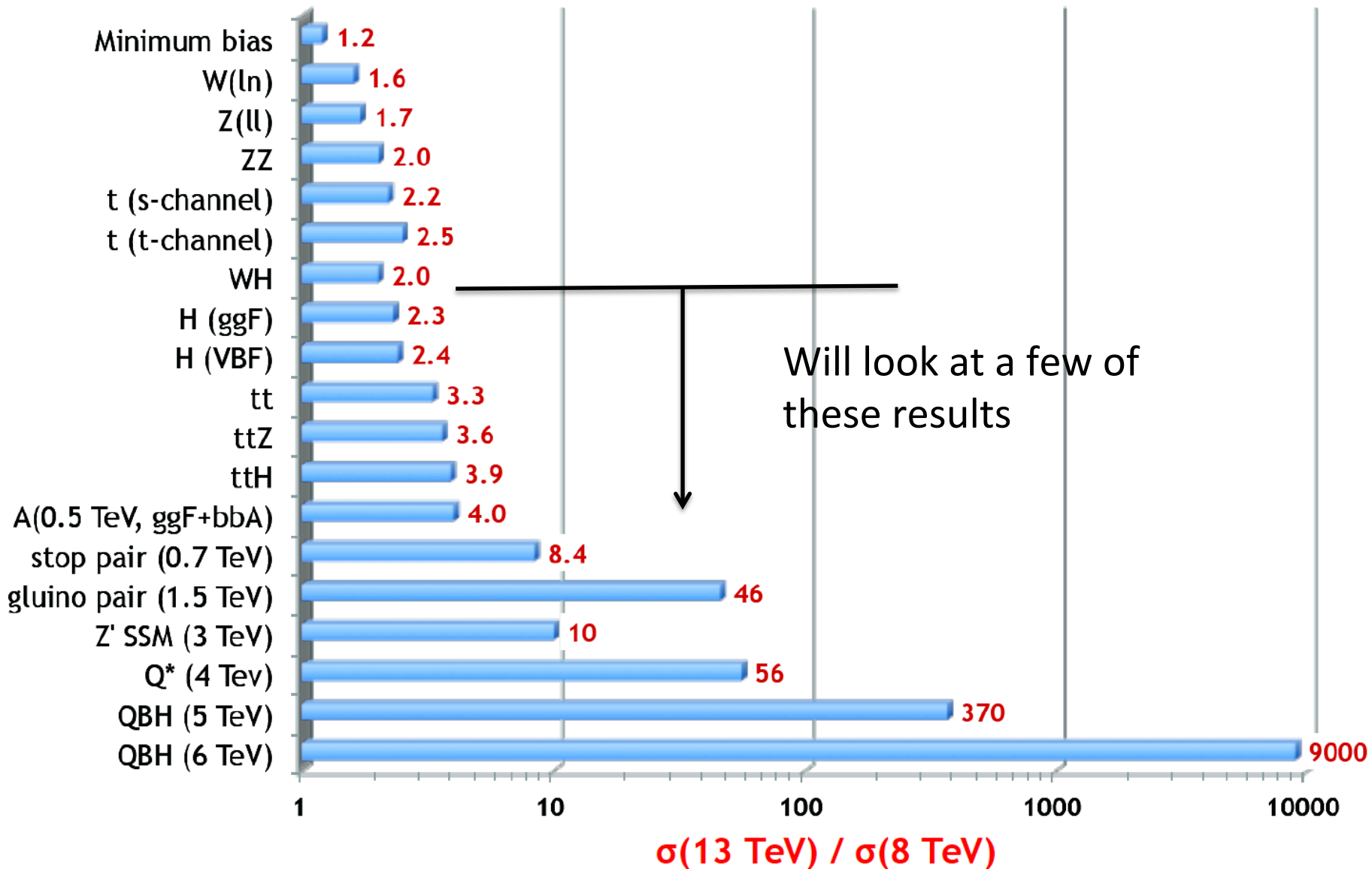
Near threshold behavior of heavy particle loops,

Resonance-continuum interference,

Single photon vs diphoton-jet,

.....

# Cross-section Increase 8→13 TeV





# Top pair cross section overview

$\sigma(13 \text{ TeV})/\sigma(8 \text{ TeV}) \sim 3.3$

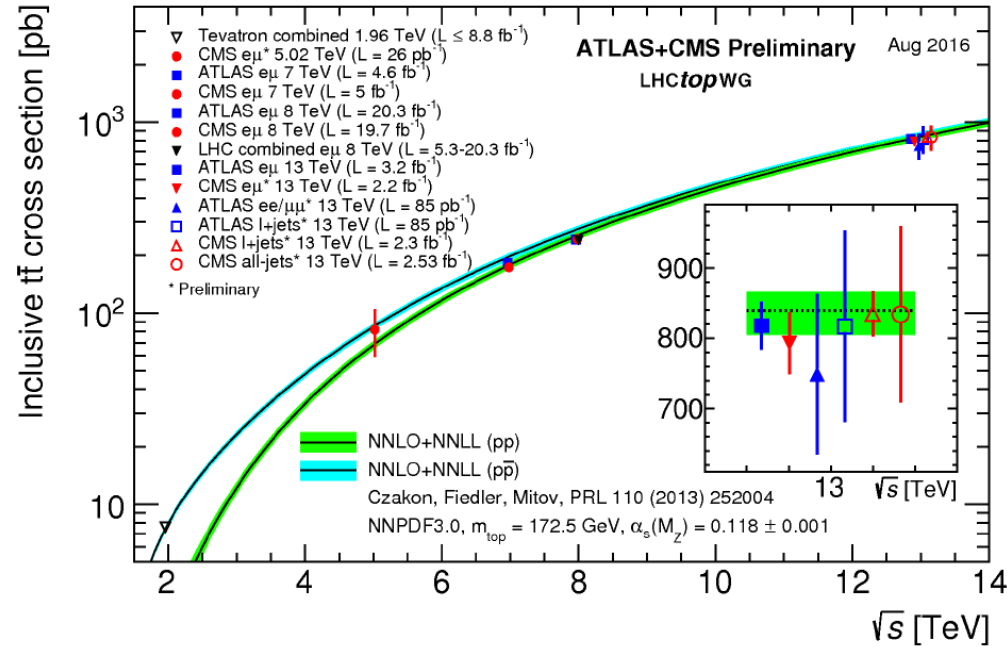
..most recent:

**ATLAS**,  $3.2 \text{ fb}^{-1}$ , 13 TeV,  
Dilept., arXiv:1606.02699

**CMS**,  $2.3 \text{ fb}^{-1}$ , 13 TeV, l+jets  
CMS-PAS-TOP-16-006

**CMS**,  $2.53 \text{ fb}^{-1}$ , 13 TeV, all jets  
CMS-PAS-TOP-16-013

**CMS**,  $26 \text{ pb}^{-1}$ , 5 TeV, dilept.  
CMS-PAS-TOP-16-015



LHC and Tevatron results consistent and in agreement with NNLO+NNLL  
over a large range of centre-of-mass energies

Ulla Blumenschein, Top and EW measure

Precision  $\pm(3.9\text{-}4.4)\%$  (7-13 TeV) better than  
NNLO+NNLL predictions ( $\sim 5\%$ )

High  $t\bar{t}$  statistics  $\rightarrow$  detailed studies  
of production properties

D Charlton

# Top @ 13TeV: Going differential

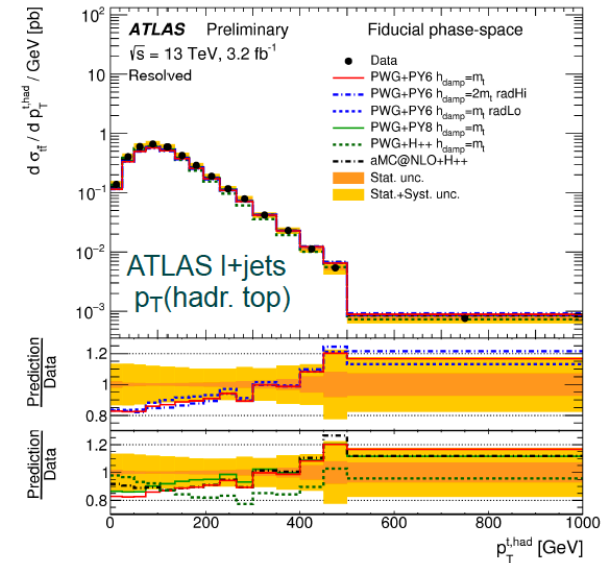
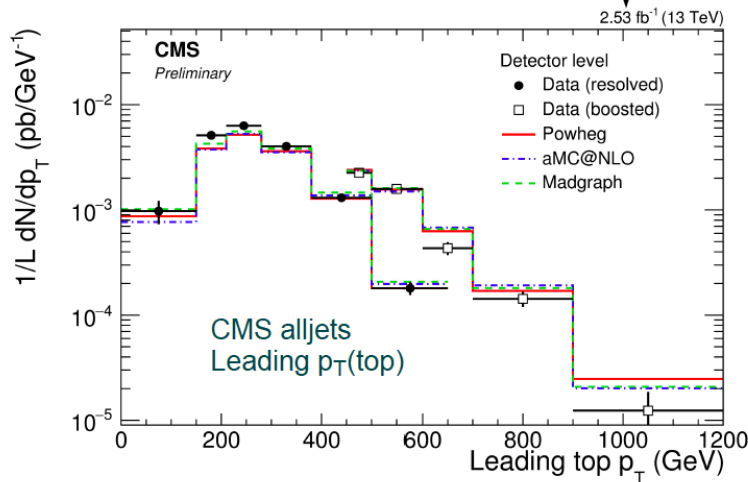
**CMS**,  $2.5\text{fb}^{-1}$ , 13TeV, l+jets, differential  $p_T$   
CMS-PAS-TOP-16-008

**CMS**,  $2.2\text{fb}^{-1}$ , 13TeV, dilep, differential  $p_T(t)$ ,  
 $y(t)$ ,  $y(tt)$ ,  $m(tt)$ ,  $\Delta\Phi(tt)$ , CMS-PAS-TOP-16-007

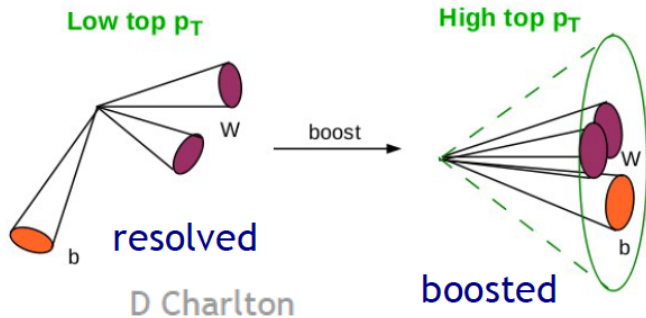
**CMS**,  $2.5\text{fb}^{-1}$ , 13TeV, all-jets, differential  $p_T$   
Resolved & boosted, CMS-PAS-TOP-16-013

**CMS**,  $2.3\text{fb}^{-1}$ , 13TeV, dilep, ttbb, ttjj  
CMS-PAS-TOP-16-010

**ATLAS**,  $3.2\text{fb}^{-1}$ , 13TeV, l+jets, differential  $p_T$   
Resolved & boosted, ATLAS-CONF-2016-040



Similar trends as in 8TeV. Top  $p_T$  modelled too hard (improves with NNLO pQCD)



Ulla Blumenschein, Top and EW measurements, ICHEP, August 9<sup>th</sup> 2016

7

Many more results available at Top 2016:  
<https://indico.cern.ch/event/486433/overview>



# Top pairs + W/Z

$$\sigma(13 \text{ TeV})/\sigma(8 \text{ TeV}) \sim 3.6$$

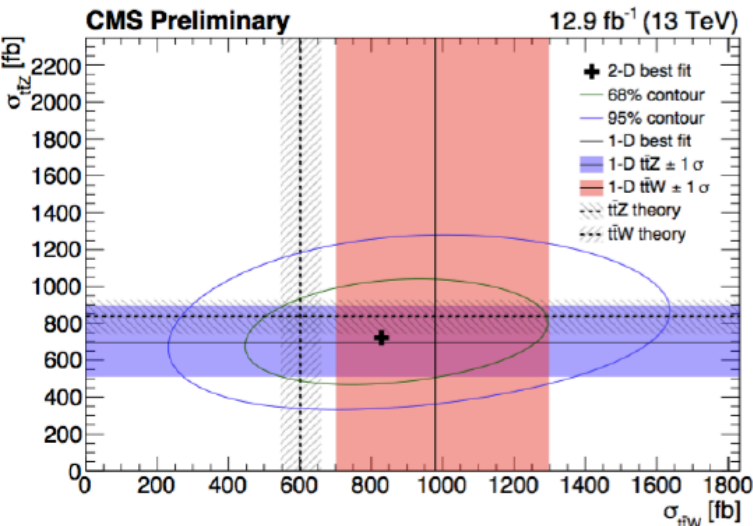
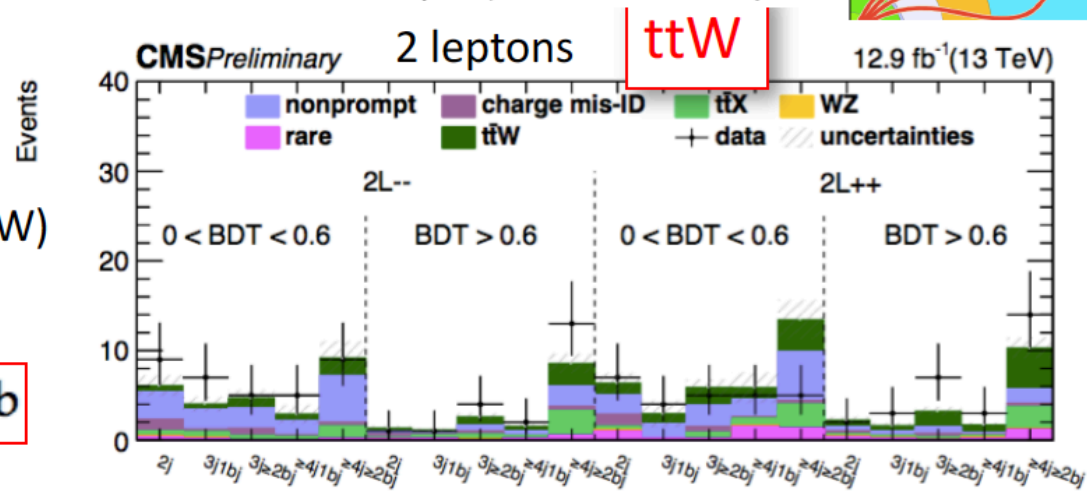
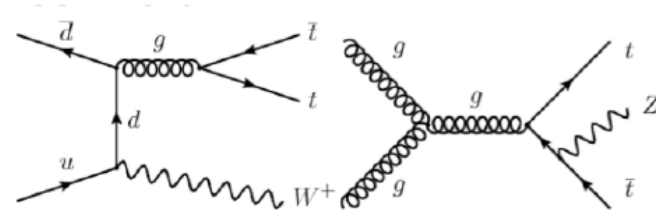
TOP-16-017



Select event with 2 SameSign leptons (TTW) or 3 or 4 leptons (TTZ)

$$\sigma(t\bar{t}Z) = 0.70_{-0.15}^{+0.16}(\text{stat.})_{-0.12}^{+0.14}(\text{sys.}) \text{ pb}$$

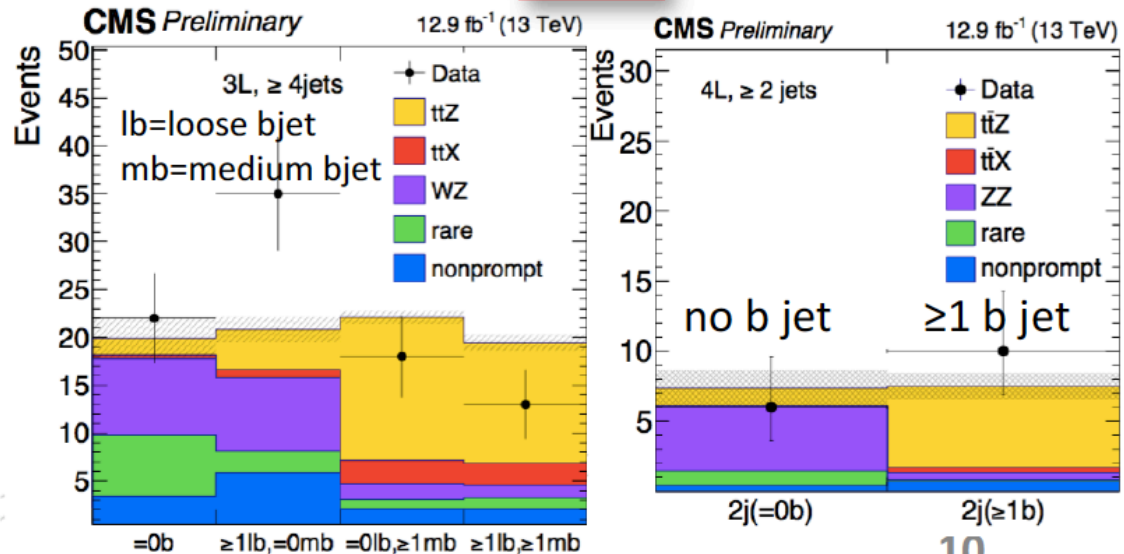
$$\sigma(t\bar{t}W) = 0.98_{-0.22}^{+0.23}(\text{stat.})_{-0.18}^{+0.22}(\text{sys.}) \text{ pb}$$



3 leptons

ttZ

4 leptons



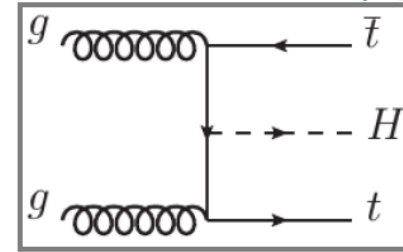
# Search for $t\bar{t}H$ production

Direct probe of top Yukawa coupling

Cross-section at 13 TeV ~4 times that at 8 TeV

Results presented with 2015+2016 data for

- $t\bar{t}H$ ,  $H \rightarrow b\bar{b}$
- $t\bar{t}H$ , multilepton final states (contributions from several decay chains)
- $t\bar{t}H$ ,  $H \rightarrow \gamma\gamma$  through  $H \rightarrow \gamma\gamma$  event categorisation



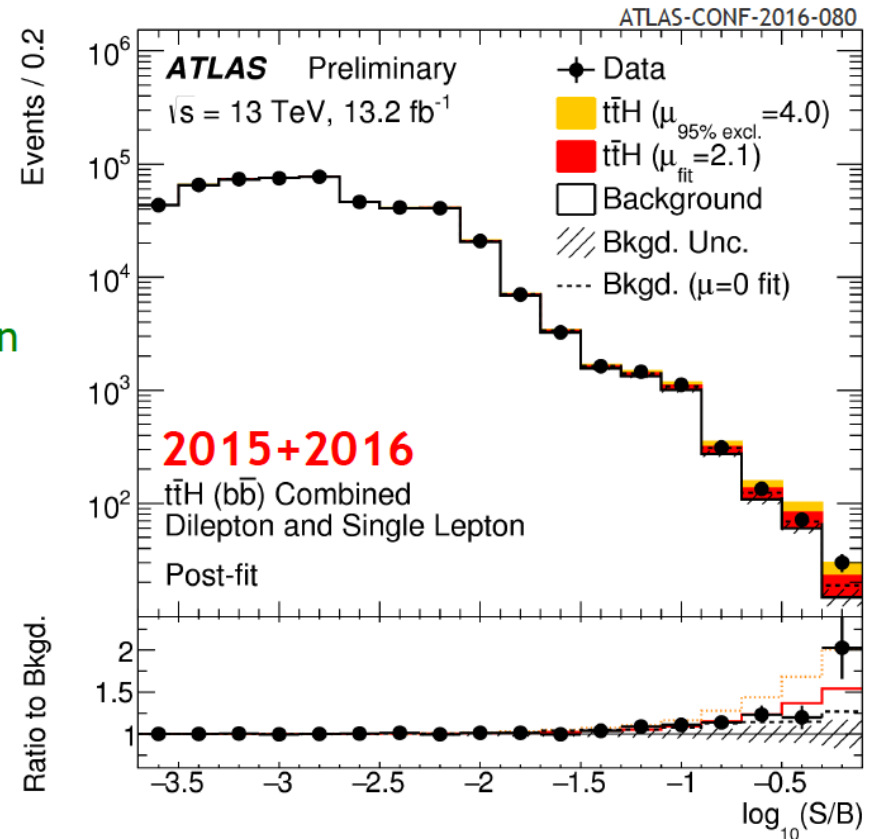
## $t\bar{t}H$ , $H \rightarrow b\bar{b}$ analysis

Complex final states

- $1\ell + 6\text{jets}$  (4 b-jets)
- $2\ell + 4\text{jets}$  (4 b-jets)

Multiple selection regions help to constrain  $t\bar{t} + \text{HF}$  production and systematic uncertainties

Plot shows events from 16 selection categories, with events ordered in signal/bkgd ratio



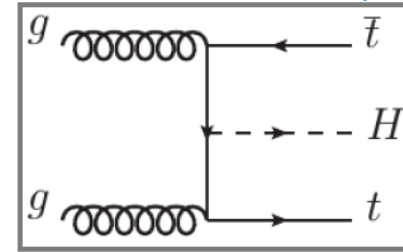
# Search for ttH production

Direct probe of top Yukawa coupling

Cross-section at 13 TeV ~4 times that at 8 TeV

Results presented with 2015+2016 data for

- ttH, H→bb
- ttH, multilepton final states (contributions from several decay chains)
- ttH, H→γγ through H→γγ event categorisation



## ttH combination

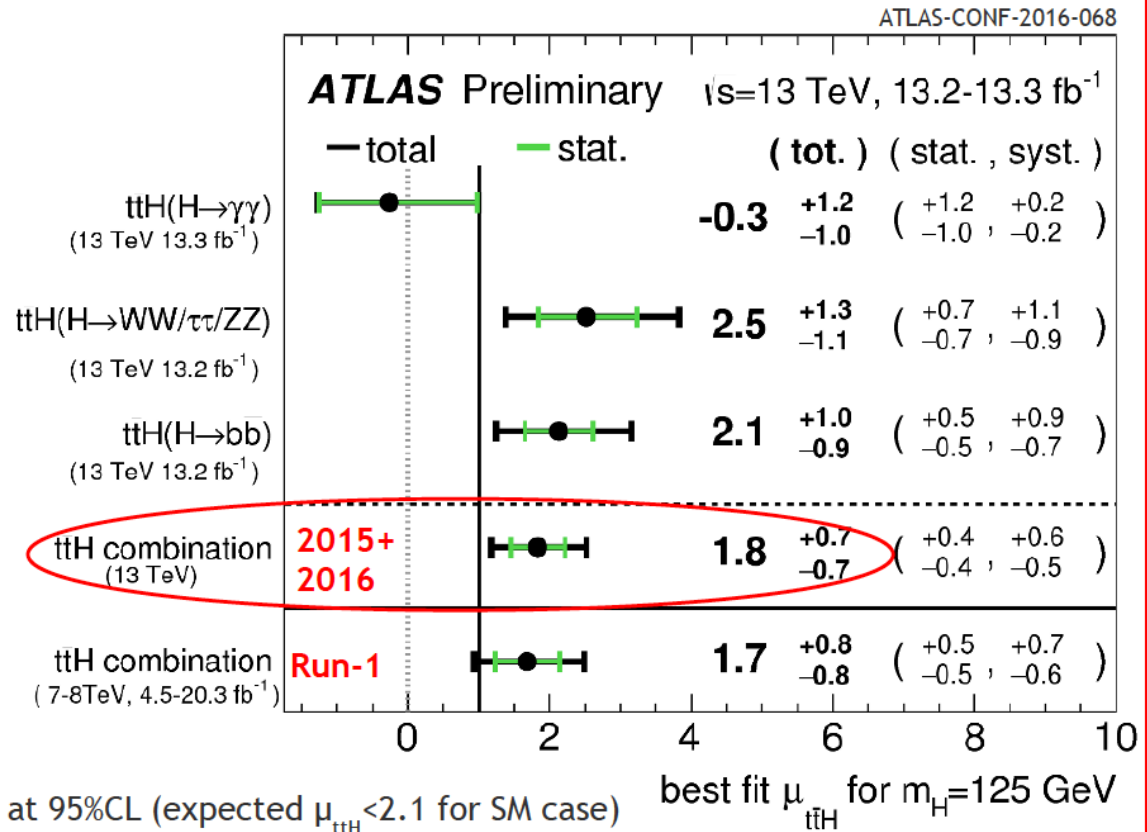
Combine all three 13 TeV analyses

Signal strength  $\mu$  expressed relative to SM expectation

Observed significance

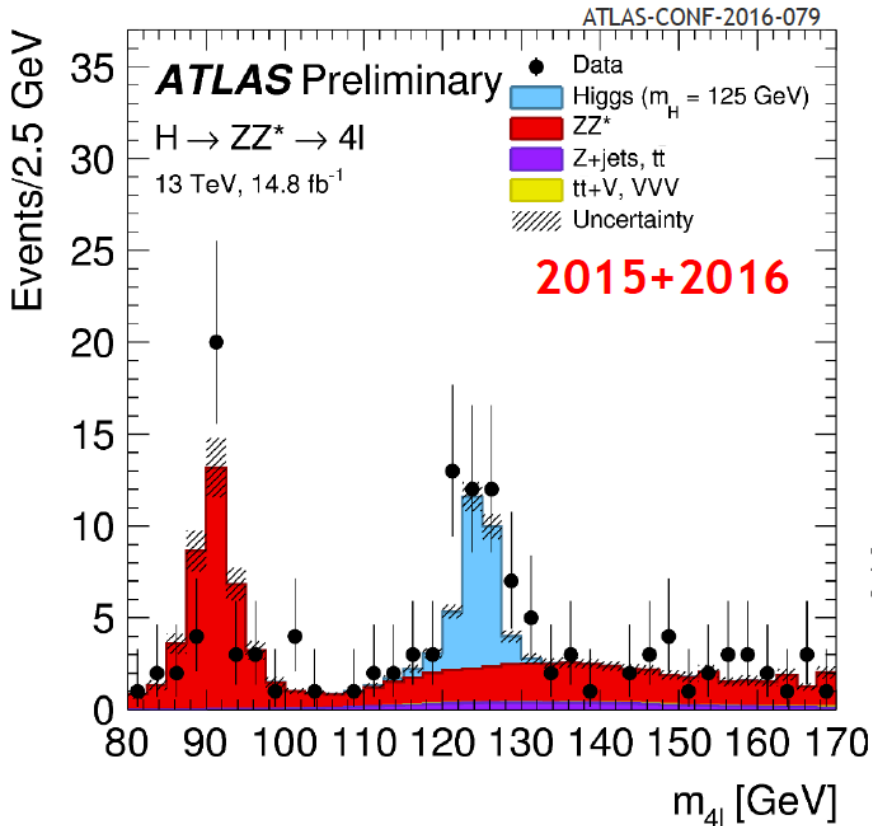
$2.8\sigma$  (expect  $1.8\sigma$ )

Cf Run-1 expected  $1.5\sigma$





# H→4ℓ & Cross-Section Combination



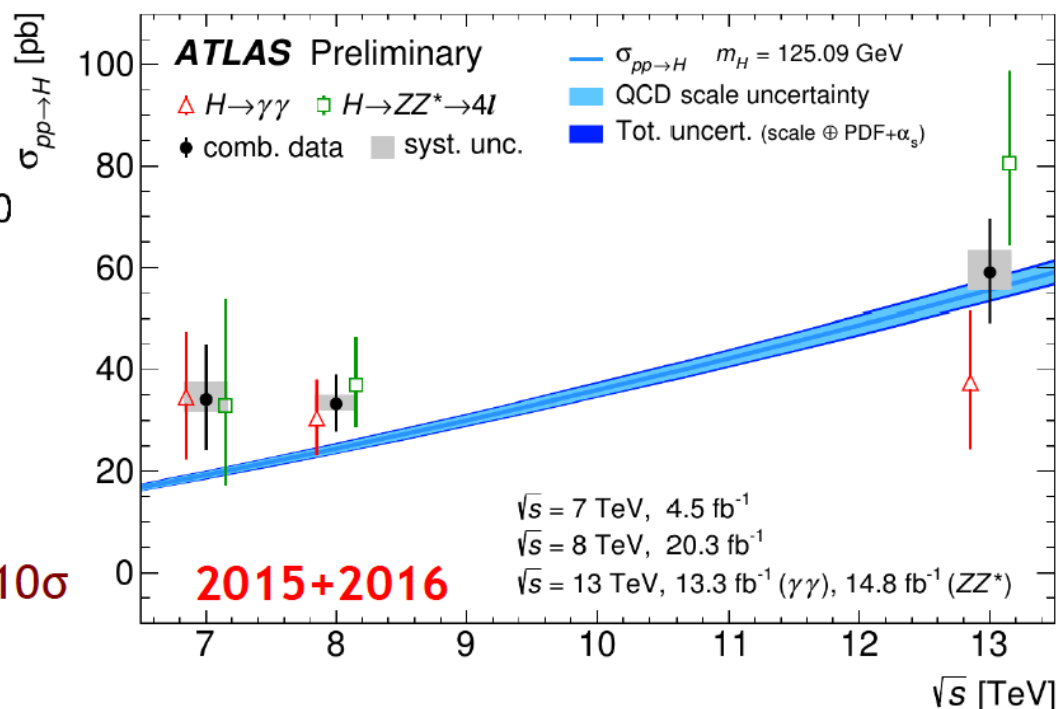
H→ZZ\*→4ℓ: event categories again used

- Clear re-observation, rate consistent with SM H expectation (1.6σ high)

Combining γγ+4ℓ channels

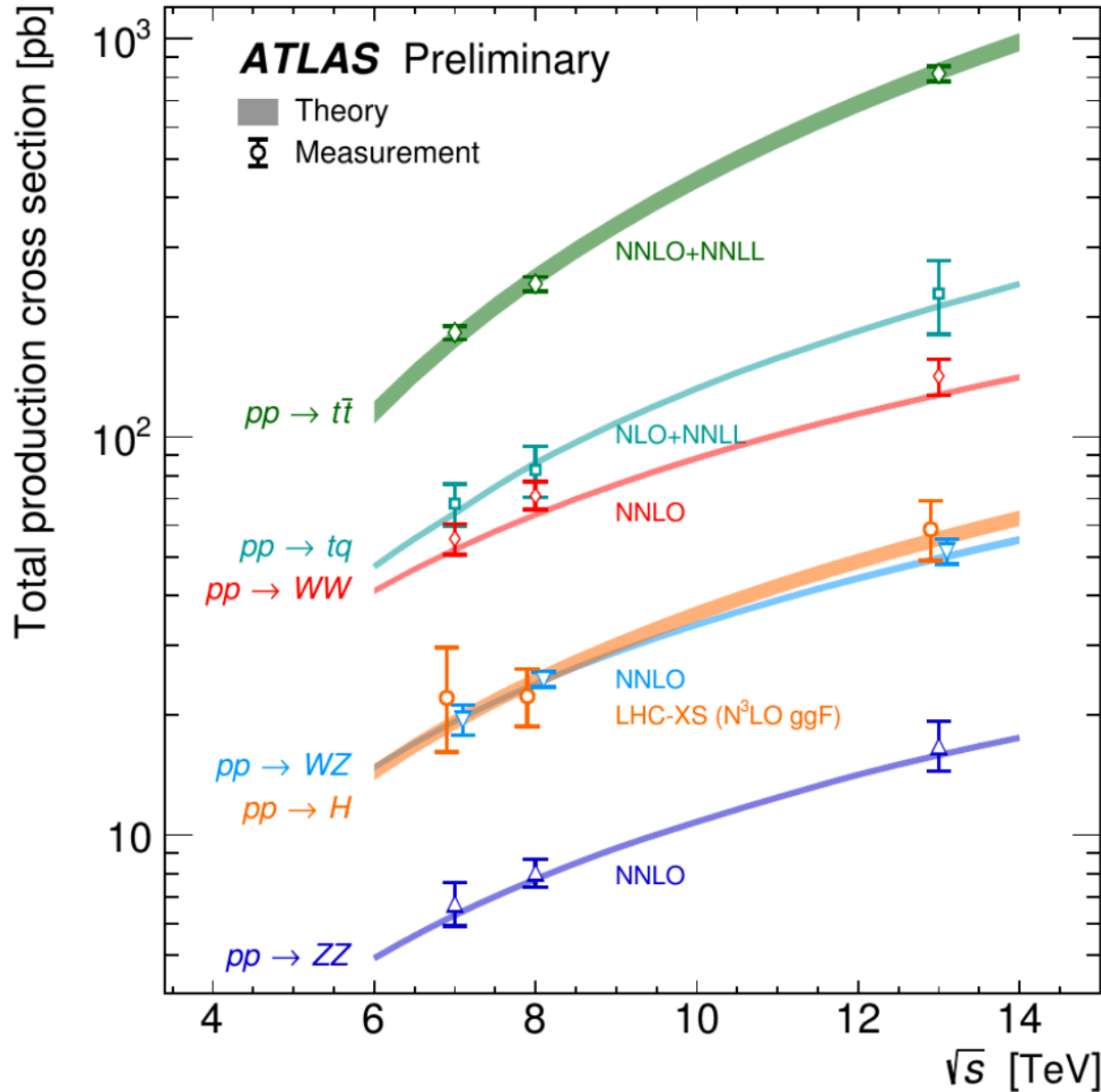
$$\sigma(pp \rightarrow H+X, 13 \text{ TeV}) = 59.0_{-9.2}^{+9.7} \text{ (stat.) }_{-3.5}^{+4.4} \text{ (syst.) pb}$$

SM prediction  $55.5_{-3.4}^{+2.4} \text{ pb}$



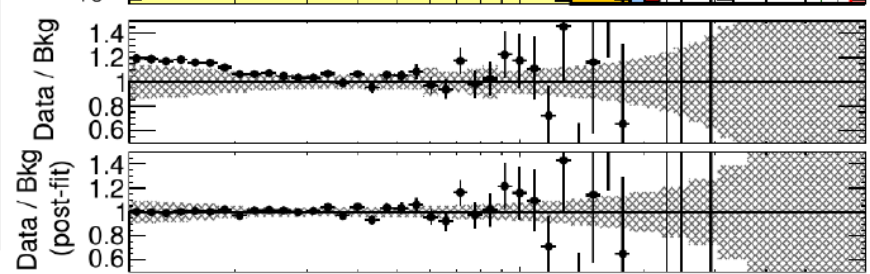
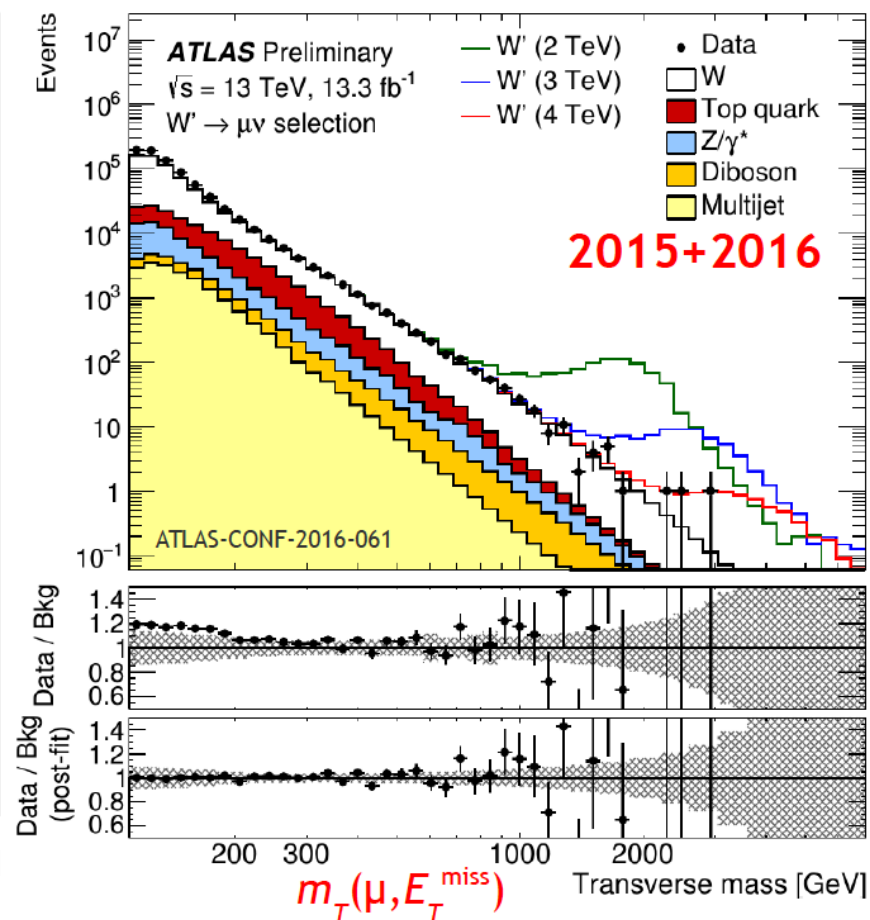
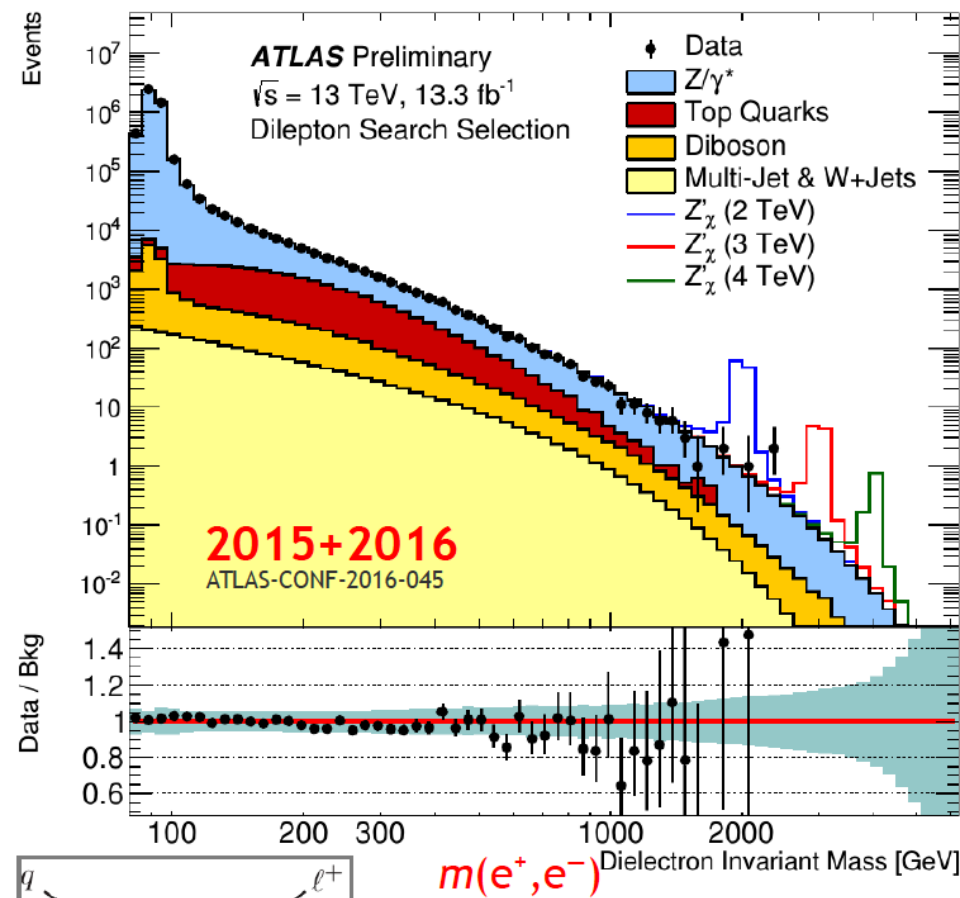
See also yesterday's LHC seminar:  
<https://indico.cern.ch/event/555813/>

Overall significance at 13 TeV ~10σ



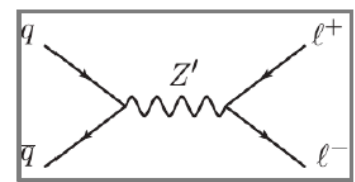
- $pp \rightarrow t\bar{t}$   
 7 TeV, 4.6 fb<sup>-1</sup>, Eur. Phys. J. C 74:3109 (2014)  
 8 TeV, 20.3 fb<sup>-1</sup>, Eur. Phys. J. C 74:3109 (2014)  
 13 TeV, 3.2 fb<sup>-1</sup>, arXiv:1606.02699
- $pp \rightarrow tq$   
 7 TeV, 4.6 fb<sup>-1</sup>, PRD 90, 112006 (2014)  
 8 TeV, 20.3 fb<sup>-1</sup>, ATLAS-CONF-2014-007  
 13 TeV, 3.2 fb<sup>-1</sup>, ATLAS-CONF-2015-079
- $pp \rightarrow WW$   
 7 TeV, 4.6 fb<sup>-1</sup>, PRD 87, 112001 (2013)  
 8 TeV, 20.3 fb<sup>-1</sup>, CERN-EP-2016-186  
 13 TeV, 3.2 fb<sup>-1</sup>, ATLAS-CONF-2016-090
- $pp \rightarrow WZ$   
 7 TeV, 4.6 fb<sup>-1</sup>, Eur. Phys. J. C (2012) 72:2173  
 8 TeV, 20.3 fb<sup>-1</sup>, PRD 93, 092004 (2016)  
 13 TeV, 3.2 fb<sup>-1</sup>, arXiv:1606.04017
- $pp \rightarrow H$   
 7 TeV, 4.5 fb<sup>-1</sup>, Eur. Phys. J. C76 (2016) 6  
 8 TeV, 20.3 fb<sup>-1</sup>, Eur. Phys. J. C76 (2016) 6  
 13 TeV, 13.3 fb<sup>-1</sup>, CONF-HIGG-2016-28
- $pp \rightarrow ZZ$   
 7 TeV, 4.6 fb<sup>-1</sup>, JHEP 03, 128 (2013)  
 8 TeV, 20.3 fb<sup>-1</sup>, ATLAS-CONF-2013-020  
 13 TeV, 3.2 fb<sup>-1</sup>, PRL 116, 101801 (2016)

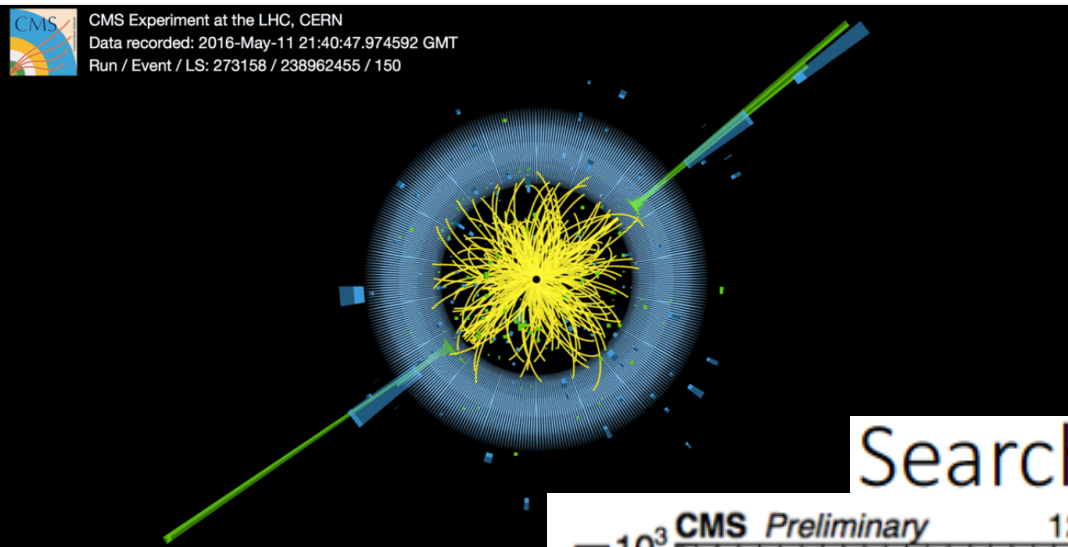
# Dilepton Resonance Searches



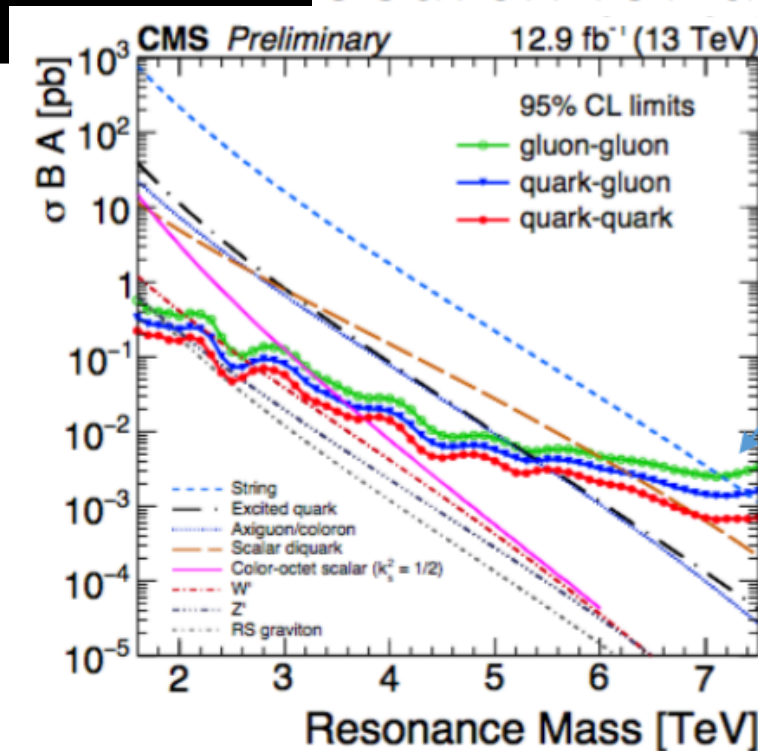
$Z'_{SSM}$  (@95%CL):  $m > 4.05 \text{ TeV}$   
 (Run-1  $m > 2.90 \text{ TeV}$ )

$W'$  (@95%CL):  $m > 4.74 \text{ TeV}$   
 (Run-1  $m > 3.24 \text{ TeV}$ )





# Search for di-jets resonances

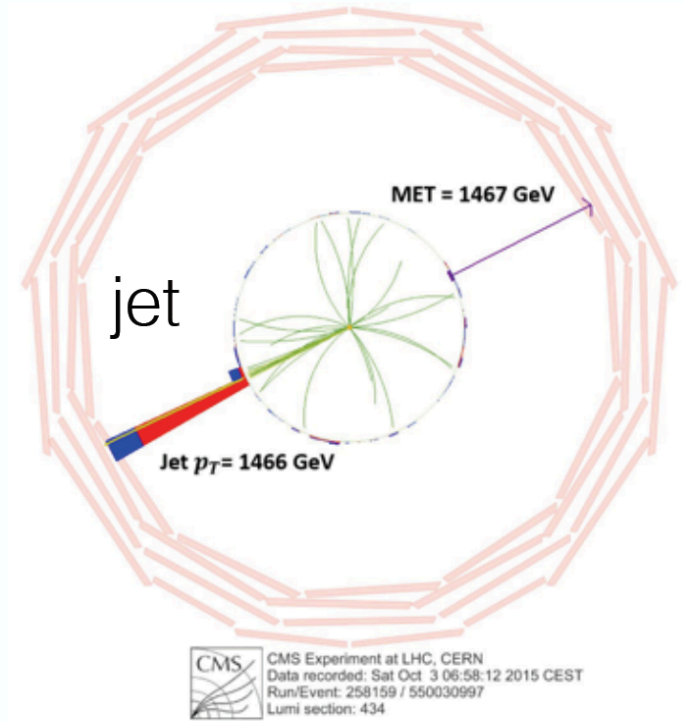
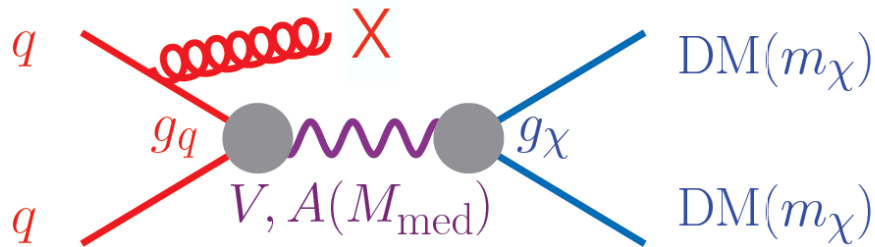


Strongest limit:  
STRING resonances  
excluded up to 7.4 TeV

# Collider Dark Matter Signature - Mono-X

ET<sup>miss</sup>+X a.k.a. Mono-X

- X from ISR jet, b, t,  $\gamma$ , W, Z



CMS  
 CMS Experiment at LHC, CERN  
 Data recorded: Sat Oct 3 06:58:12 2015 CEST  
 Run/Event: 258159 / 550030997  
 Lumi section: 434

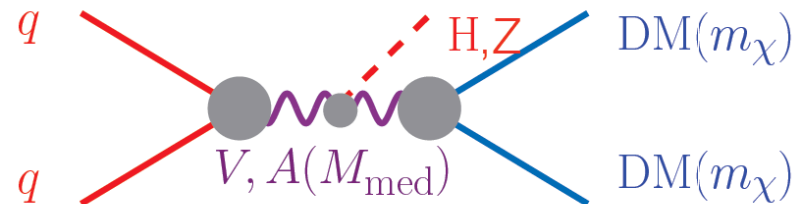
boosted  
 $H(bb\sim)$

ATLAS  
 EXPERIMENT

Run Number: 282992, Event Number: 963173182

Date: 2015-10-23 07:44:15 CEST

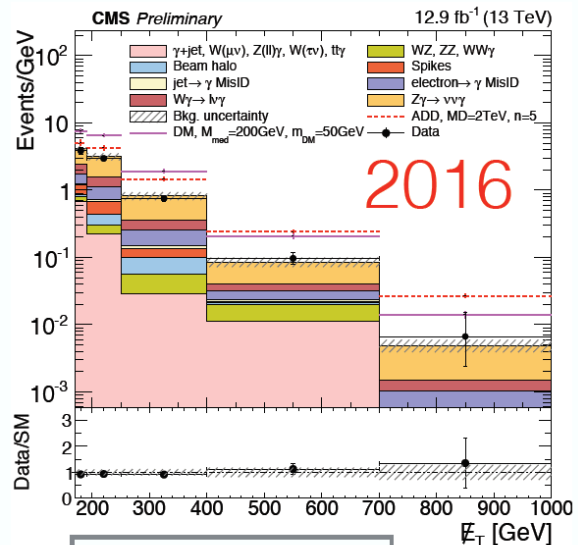
- X from mixing with mediator



- X from paired  $t\bar{t}$ ,  $b\bar{b}$



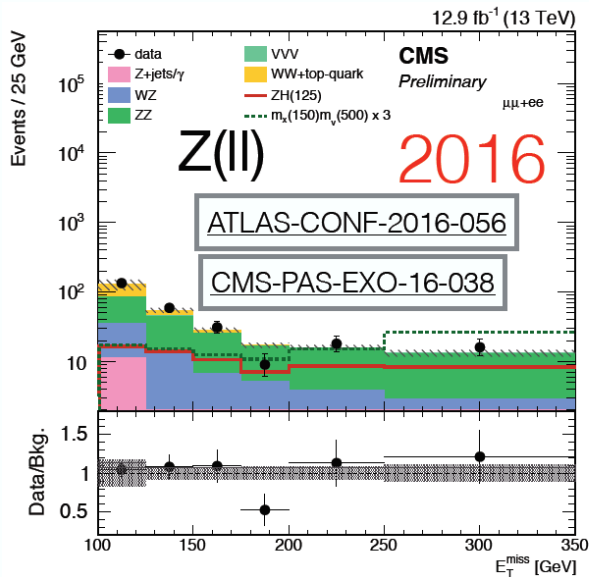
## ET<sup>miss</sup>+ $\gamma$



ATLAS-CONF-2015-080

CMS-PAS-EXO-16-039

## ET<sup>miss</sup> + W/Z



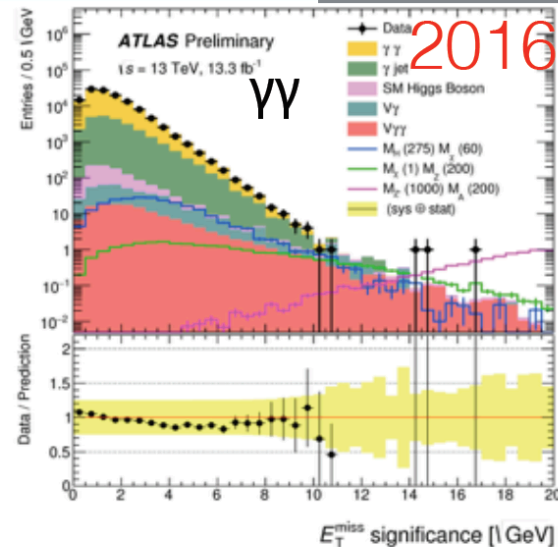
Z(H) 2016  
ATLAS-CONF-2016-056  
CMS-PAS-EXO-16-038

EXOT-2015-08

CMS-PAS-EXO-16-037

2015

## ET<sup>miss</sup>+H

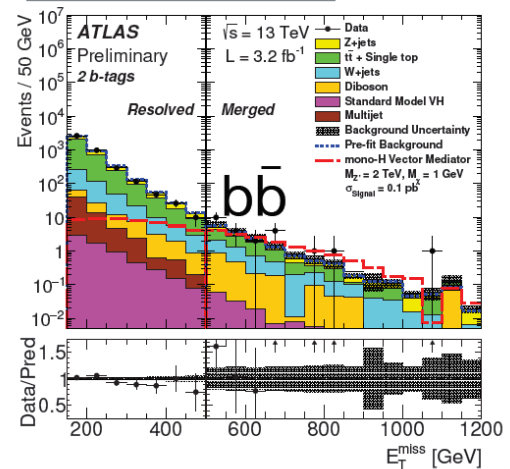
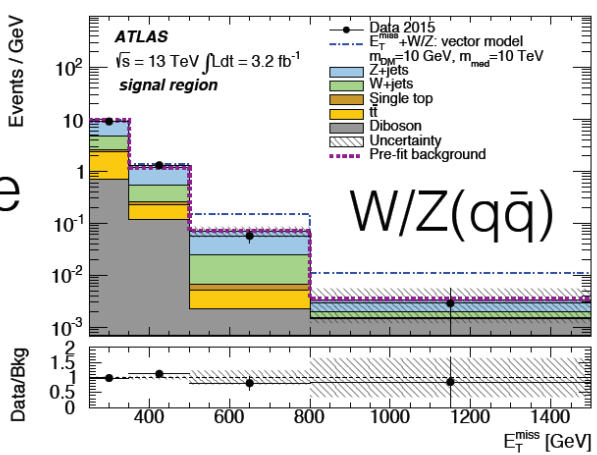


ATLAS-CONF-2016-019

CMS-PAS-EXO-16-012

2015

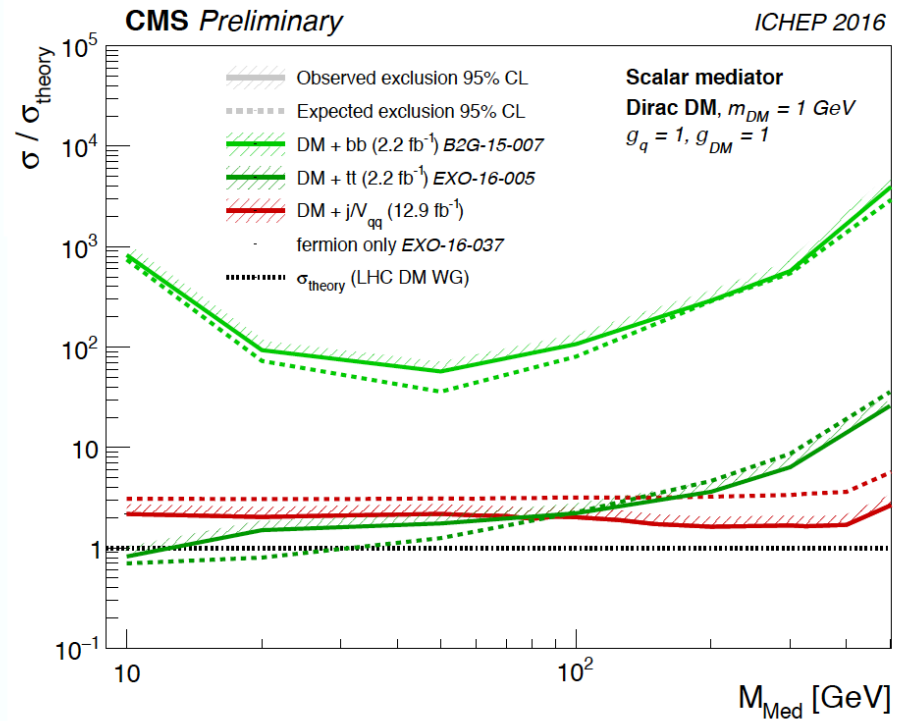
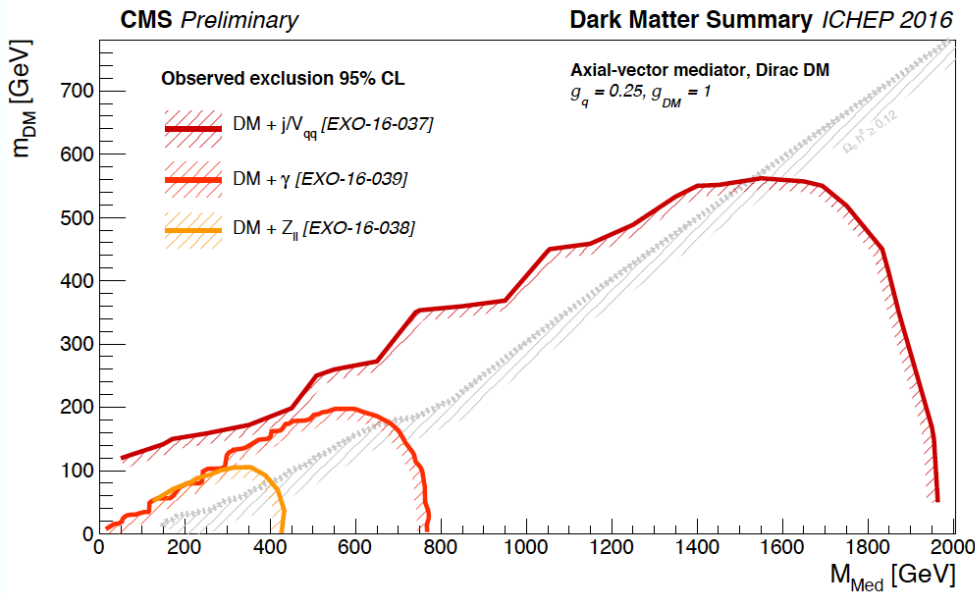
Boosted jet substructure technique is used in hadronic W/Z/H





# Dark Matter exclusion limit

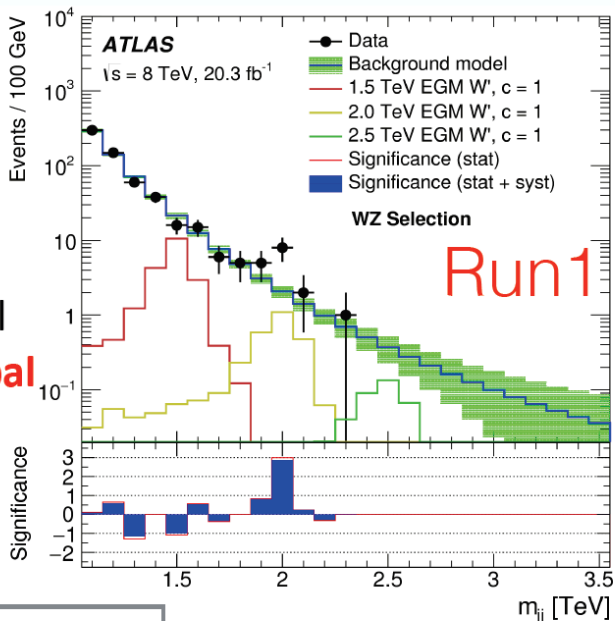
- No significant excess observed so far
- DM mass exclusion up to  $\sim 550$  GeV
- Vector Mediator mass exclusion up to 1.95 TeV





# Revisit diboson excesses in Run1

JHEP12(2015)055

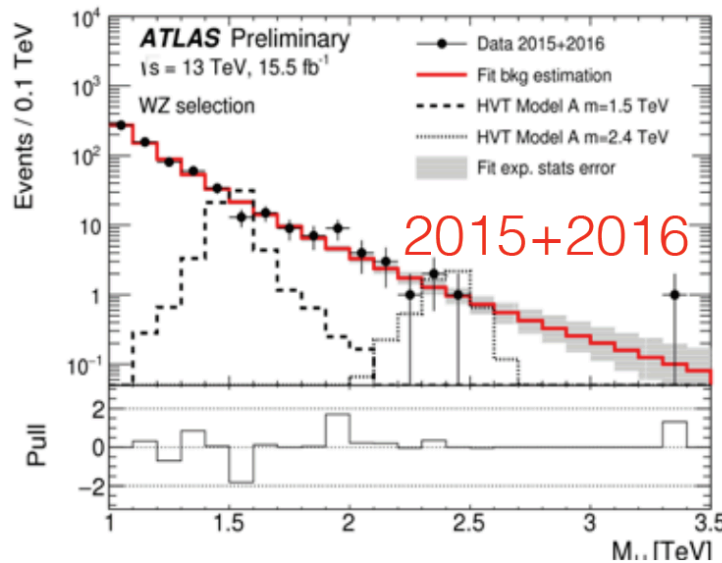


m = 2 TeV  
3.4 $\sigma$  local  
2.5 $\sigma$  global

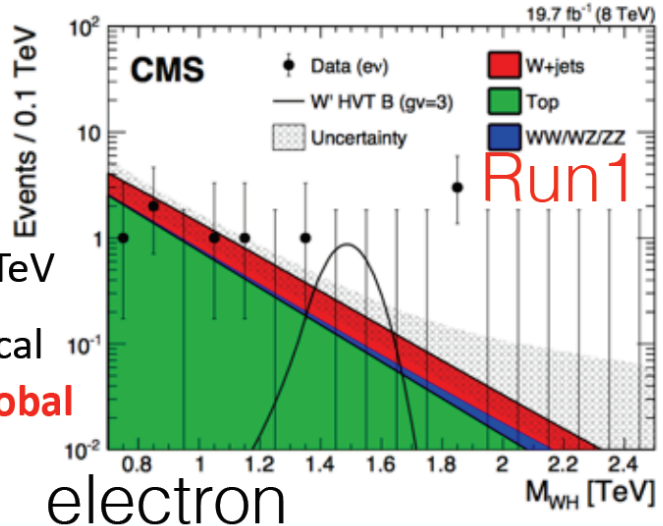
Excesses not confirmed in Run2



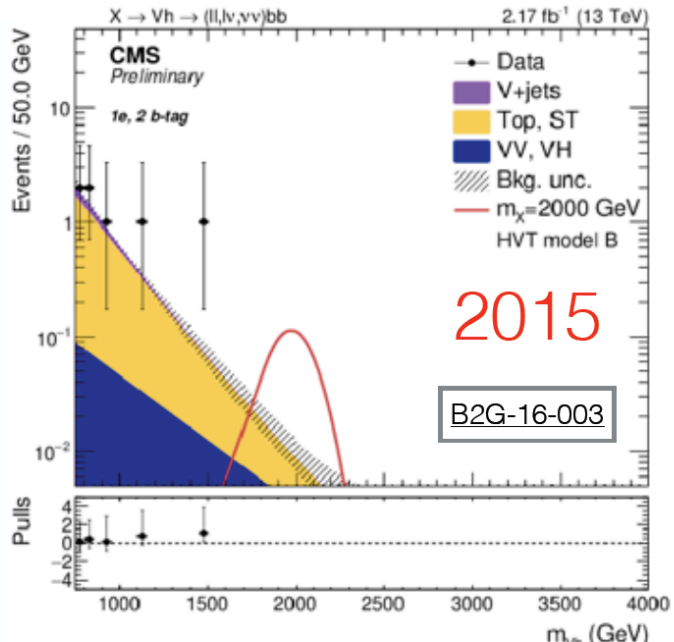
ATL-CONF-2016-055



EPJC 76 (2016) 237



m = 1.8 TeV  
2.9 $\sigma$  local  
1.9 $\sigma$  global

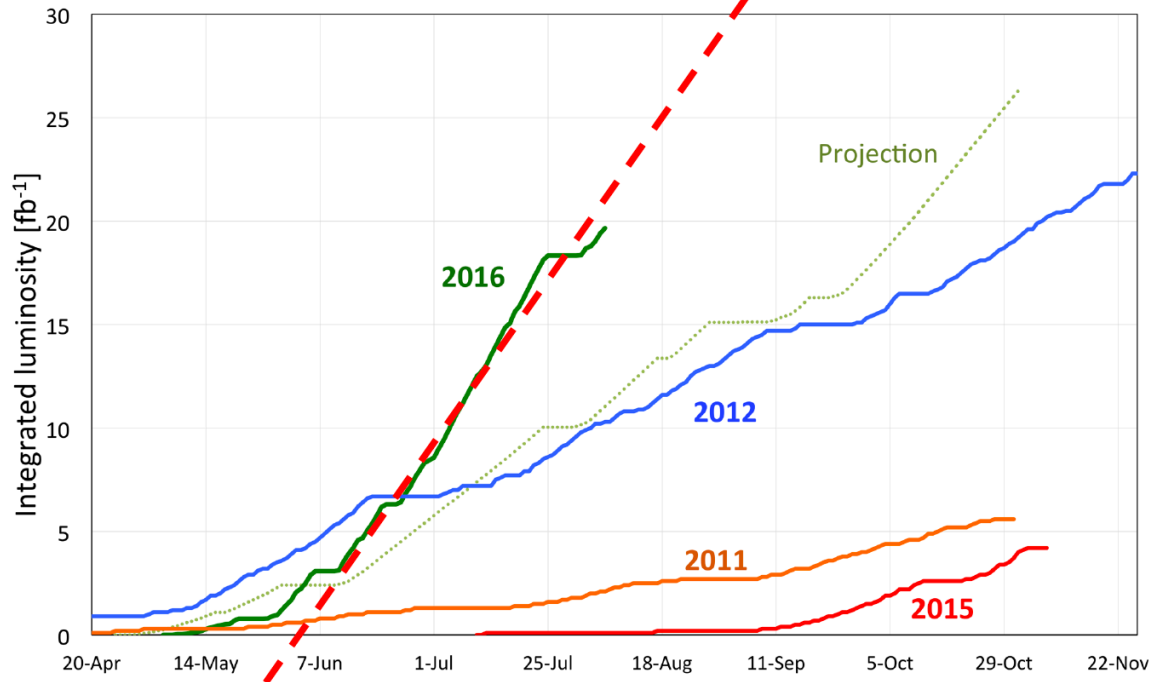


B2G-16-003

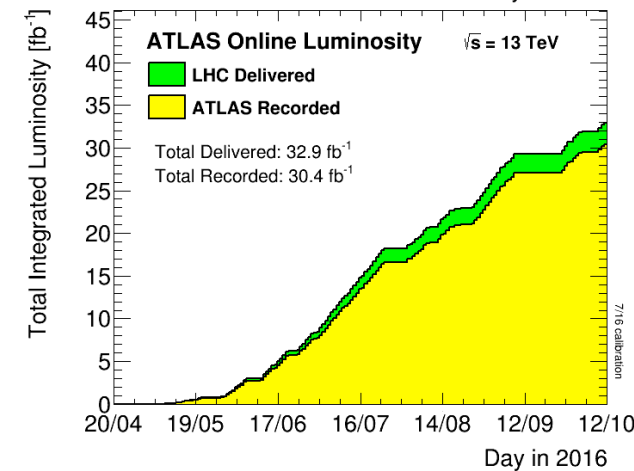
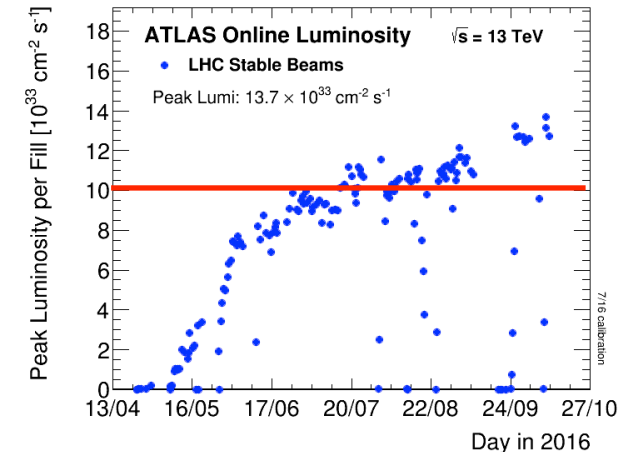
## LHC Accelerator Performance

Mike Lamont

Please don't do this!



Current plots (11/10/16)



- Peak luminosity limited to  $\sim 1.7 \times 10^{34}$  by inner triplets
- $\sim 40 \text{ fb}^{-1}/\text{year}$  in 2017 and 2018

# (Heavy) flavour physics



# A new $B_S^0 \pi^\pm$ state claimed by DØ



[DØ: arXiv:1602.07588, PRL 117, 022003 (2016)]

Claimed observation/evidence of an exotic state

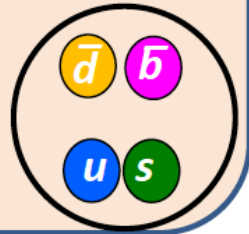
◆  $X(5568)^\pm \rightarrow B_S^0 \pi^\pm, B_S^0 \rightarrow J/\psi \phi, J/\psi \rightarrow \mu^+ \mu^-, \phi \rightarrow K^+ K^-$

$$M = 5567.8 \pm 2.9_{-1.9}^{+0.9} \text{ MeV}$$

$$\Gamma = 21.9 \pm 6.4_{-2.5}^{+5.0} \text{ MeV}$$

◆ Fraction of  $B_S^0$  from  $X^\pm$  decay:  $\rho_X^{DØ} = (8.6 \pm 1.9 \pm 1.4) \%$

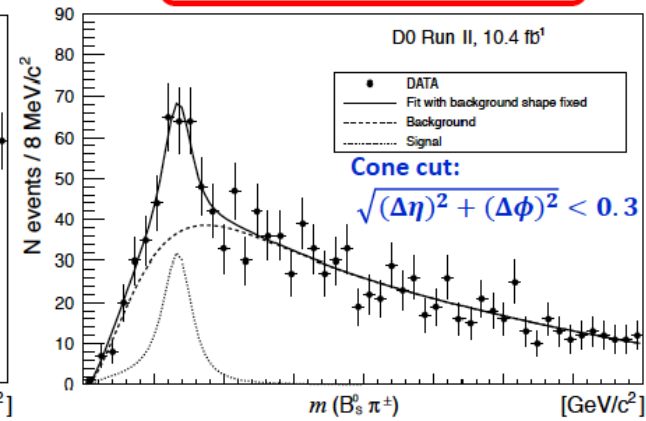
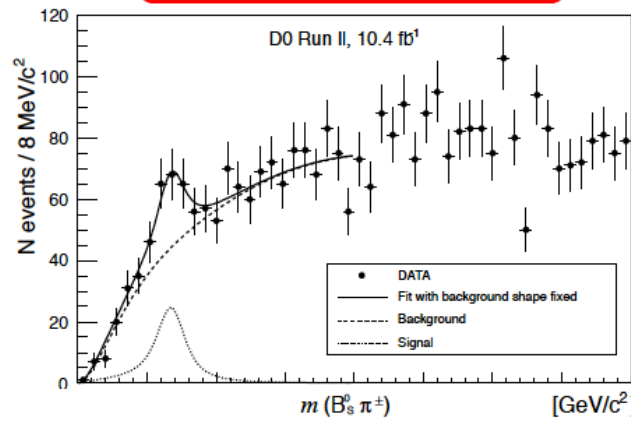
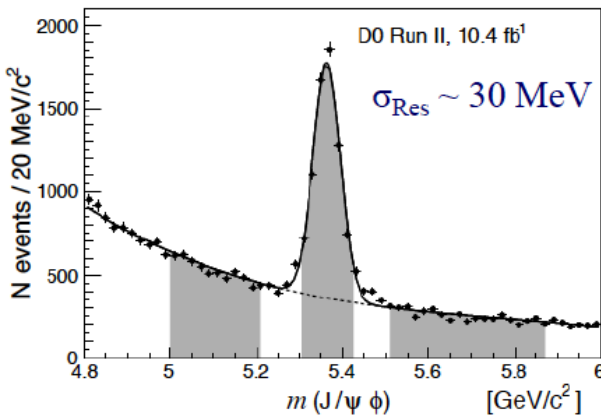
◆ If confirmed, would be unique with 4 different flavours



$N(B_S) \sim 5500$

$N(X) = 106 \pm 23$

$N(X) = 133 \pm 31$



$3.9 \sigma$

$5.1 \sigma$

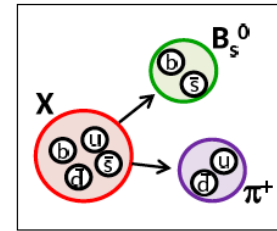
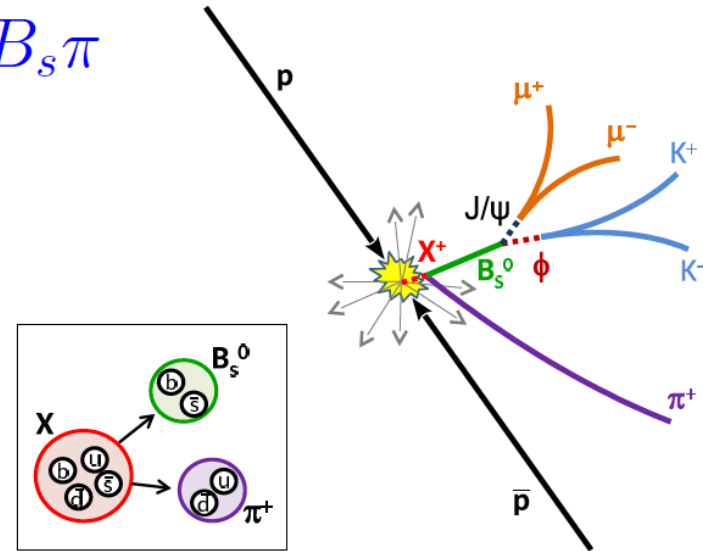
Signal significance

# Exotic states at D0

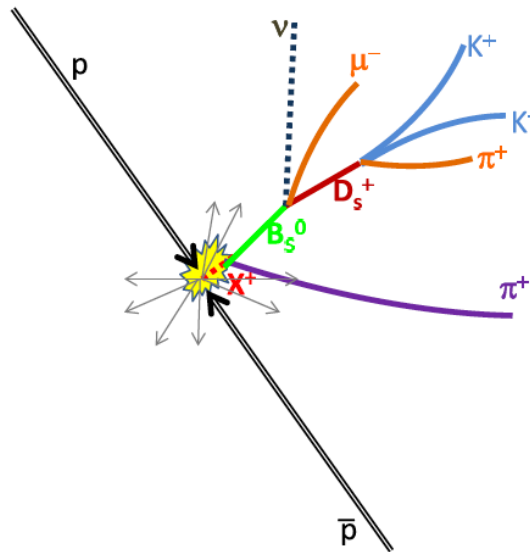
Exotic states at D0

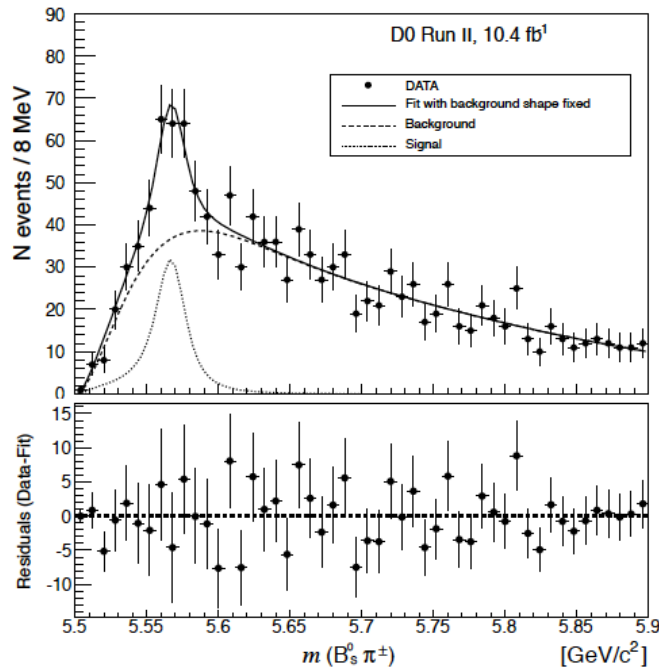
$$X(5568) \rightarrow B_s \pi$$

$B_s \pi^\pm$  state with  $B_s^0 \rightarrow J/\psi \phi$   
(PRL 117, 022003 (2016))



New:  $B_s^0 \rightarrow D_s \mu \nu$  channel



Results for the case with  $\Delta R$  cut

$$M_X = 5567.8 \pm 2.9 \text{ MeV}$$

$$\Gamma_X = 21.9 \pm 6.4 \text{ MeV}$$

$$N = 133 \pm 31$$

Signif. (with syst and LEE)  $S = 5.1\sigma$

(“Local”  $S = 6.6\sigma$ ).

(PRL 117, 022003 (2016))

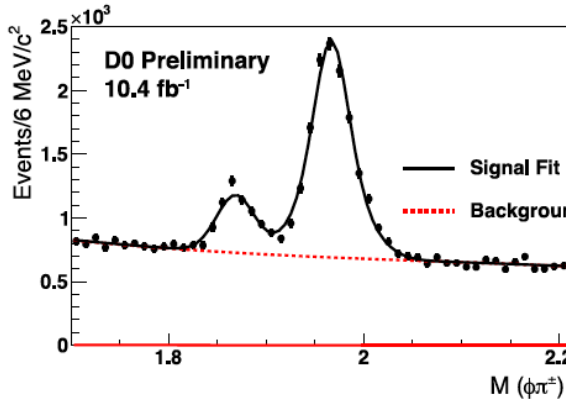
Signal is modeled by a relativistic Breit-Wigner function convolved with a Gaussian resolution of  $\sigma = 3.8 \text{ MeV}$  (MC) and multiplied by mass-dependent efficiency.

- We perform the analysis with and without a limit on the angular separation between the  $B_S^0$  and the pion:

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.3 \text{ (the “cone” cut)}$$

# New channel: $B_s^0 \rightarrow D_s \mu \nu$ reconstruction

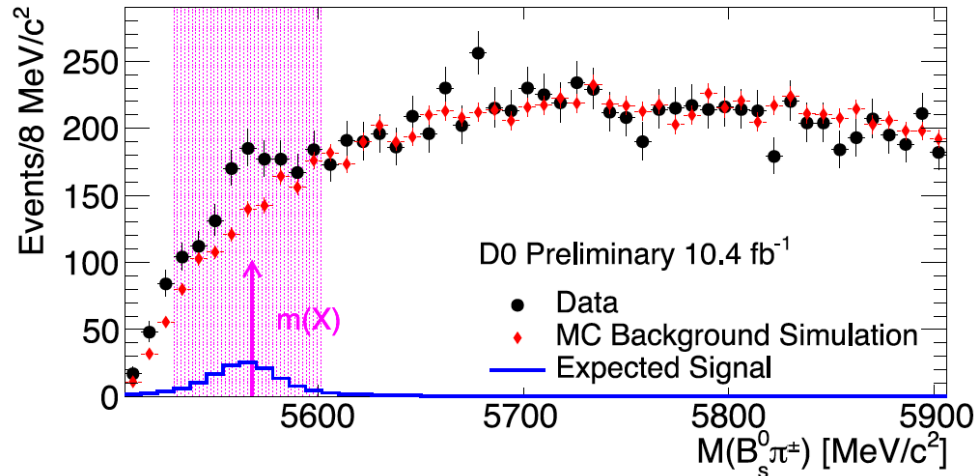
Reconstruct  $D_s \rightarrow \phi \pi$ ,  $\phi \rightarrow K^+ K^-$   
 require  $1.92 < m(\phi\pi) < 2.02$  GeV



Exotic states at D0

## Comparison of data and simulated background

We simulate the component of the background due to random combinations of  $B_s^0 \rightarrow D_s \mu \nu$  with a track assumed to be a pion and compare it to data.



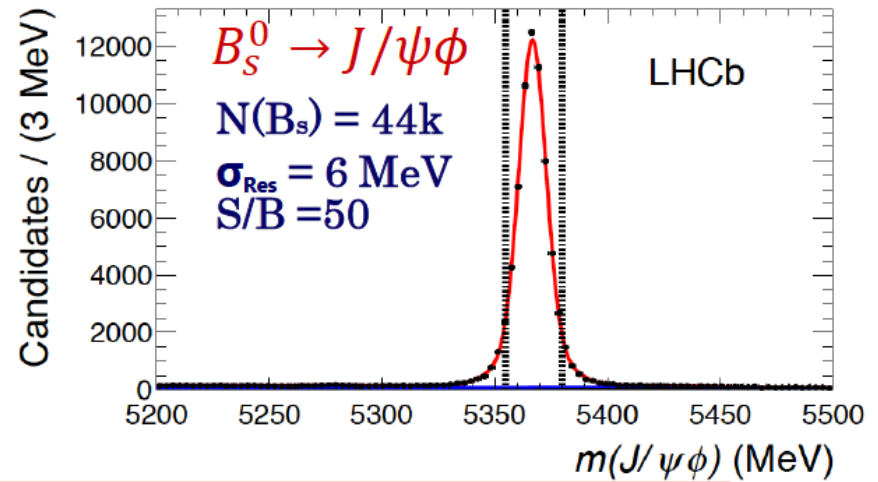
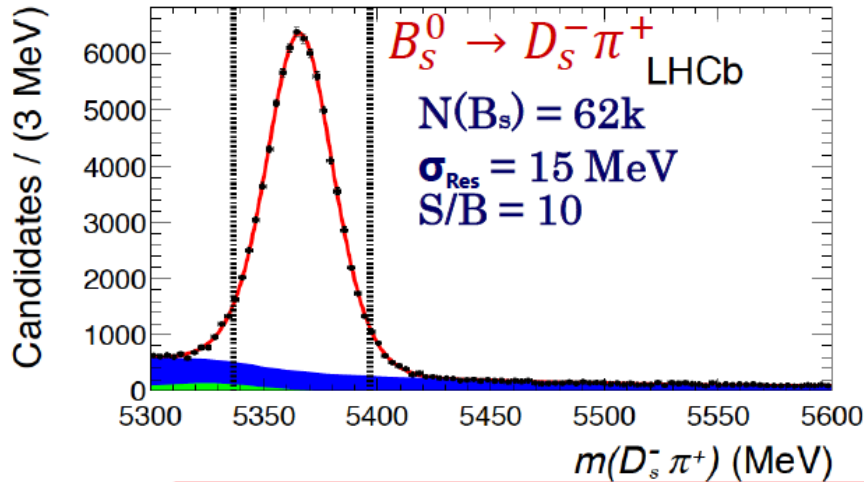
We see an enhancement whose mass, width and yield are consistent with those in the  $X(5568) \rightarrow B_s^0 \pi^\pm$ ,  $B_s^0 \rightarrow J/\psi \phi$  publication.



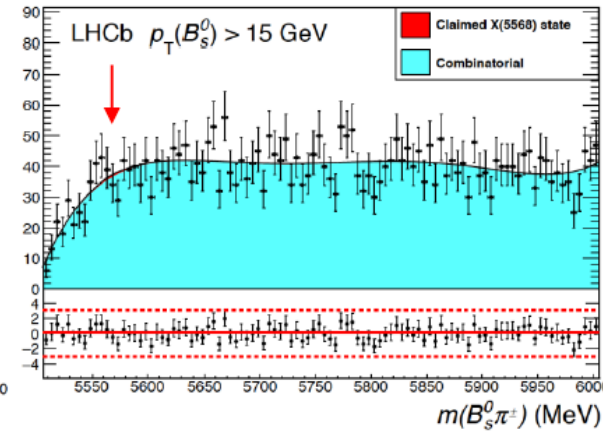
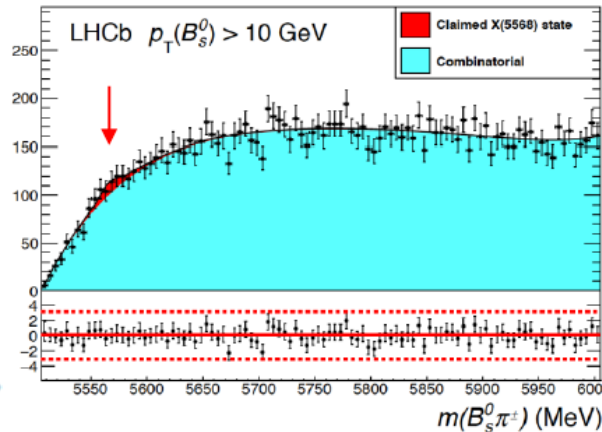
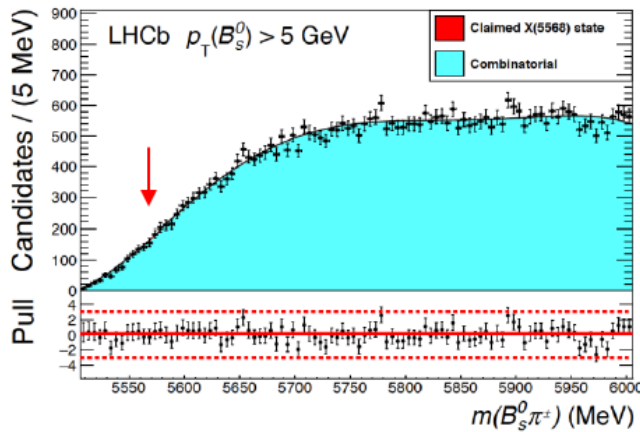
# Samples from LHCb

LHCb-PAPER-2016-029

arXiv:1608.00435



$B_s^0$  sample 20x larger and much cleaner than DØ



No evident X(5568) in  $B_s^0 \pi^\pm$  sample for 3 different  $p_T(B_s^0)$  cuts

# Upper limits



- At 90% (95%) CL

$$\rho_X^{\text{LHCb}} = \frac{\sigma(pp \rightarrow X + \text{anything}; X \rightarrow B_s^0 \pi^{\pm})}{\sigma(pp \rightarrow B_s^0 + \text{anything})}$$

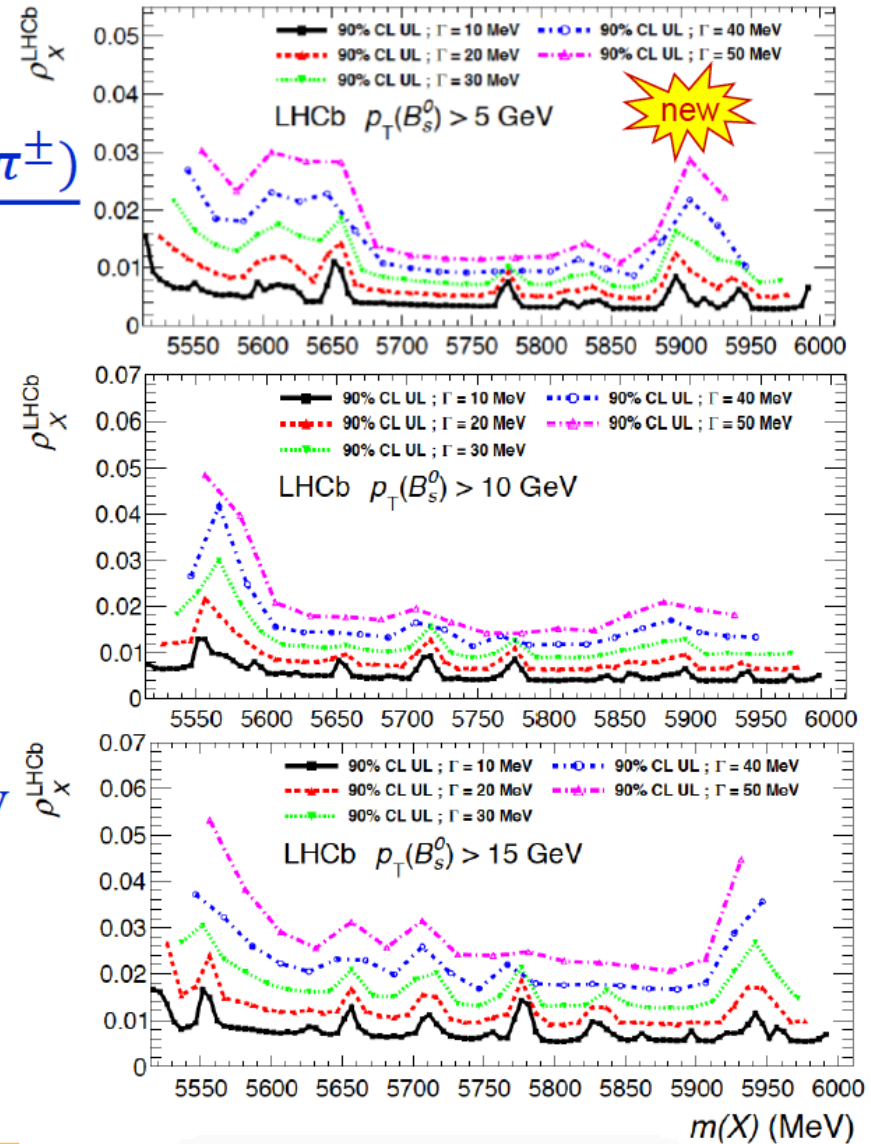
in LHCb acceptance

$$\rho_X^{\text{LHCb}}(p_T(B_s^0) > 5 \text{ GeV}) < 0.011 \text{ (0.012)}$$

$$\rho_X^{\text{LHCb}}(p_T(B_s^0) > 10 \text{ GeV}) < 0.021 \text{ (0.024)}$$

$$\rho_X^{\text{LHCb}}(p_T(B_s^0) > 15 \text{ GeV}) < 0.018 \text{ (0.020)}$$

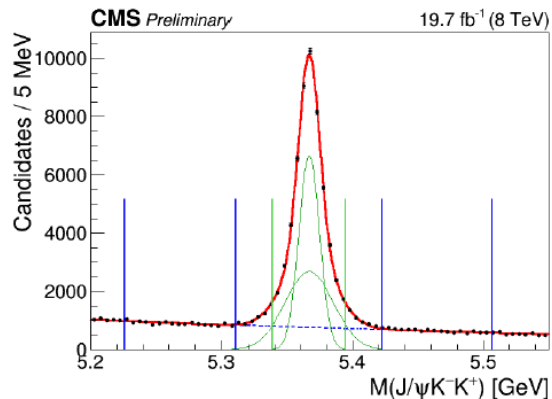
- No significant  $B_s^0 \pi^{\pm}$  states for any mass and width below 6 GeV
- Upper limit is set as a function of  $m(X)$  and  $\Gamma(X)$



# Search for $X^+(5568) \rightarrow B_s \pi^+$



- DZero reported the observation of a tetraquark candidate in  $X^+(5568) \rightarrow B_s \pi^+$
- LHCb reported a non-confirmation result of these candidate.
- CMS has recollected several thousands of  $B_s \rightarrow J/\psi \phi$  decays on what to look for.



$$\rho_X \equiv \frac{\sigma(pp \rightarrow X(5568) + \text{anything}) \times B(X(5568) \rightarrow B_s \pi^\pm)}{\sigma(pp \rightarrow B_s + \text{anything})} = \frac{N_X \epsilon_{B_s}}{N_{B_s} \epsilon_X}$$

EDUARD DE LA CRUZ BURELO

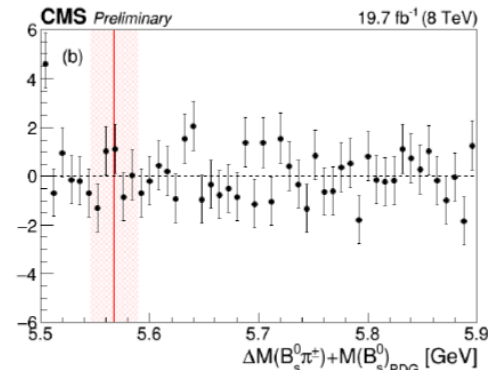
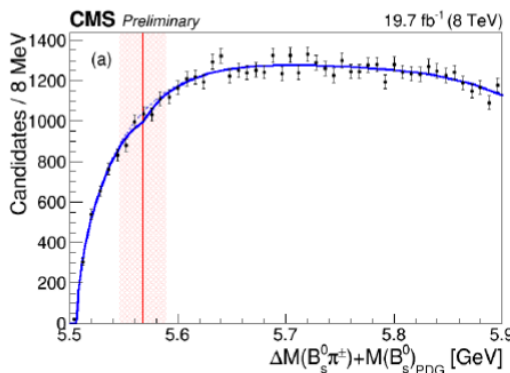
8/4/2016



# Search for $X^+(5568) \rightarrow B_s \pi^+$



- Sculpting effects near threshold (in D0)?
- Needs more study



$\rho_X < 3.9\% \text{ @}95\% \text{ C.L.}$

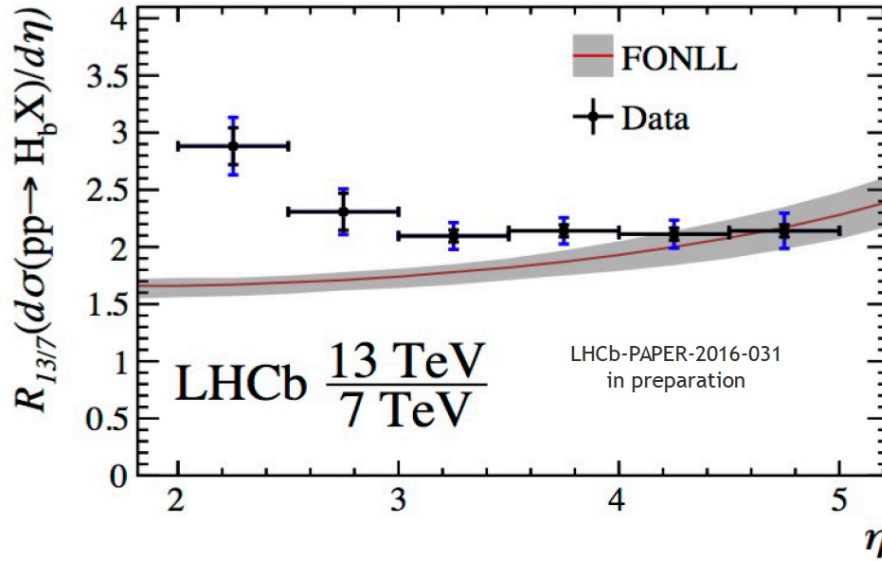
$\rho_X^{DZero} = 8.6 \pm 1.9 \text{ (stat)} \pm 1.4 \text{ (syst.) \%}$

# $b\bar{b}$ Cross-Section at 7 and 13 TeV



LHCb has measured the cross-section for the process  $pp \rightarrow b\bar{b}X$  at both 7 and 13 TeV centre-of-mass energies, in the pseudorapidity range  $2 < \eta < 5$

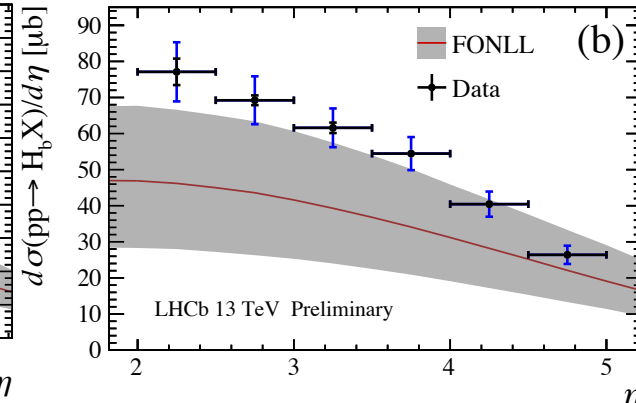
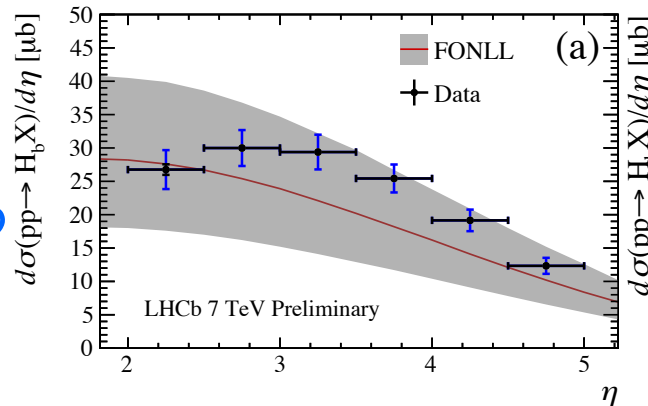
- The measurement is made using semileptonic decays of b-hadrons



The ratio of 13 to 7 TeV cross-sections appears to depart from FONLL theory predictions at low  $\eta$

- Calls for further theoretical progress

M. Artuso





## Why study CPV ?

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Violation of CP symmetry is a necessary condition for the Baryon Asymmetry of the Universe [1]

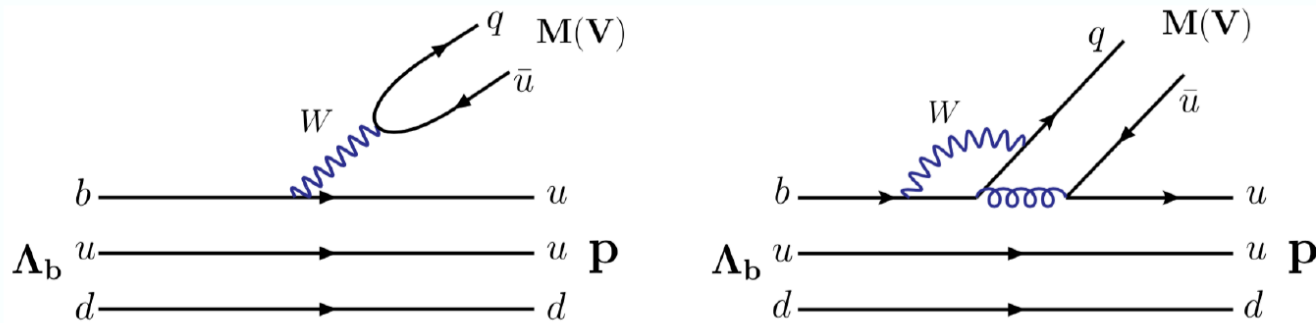
CPV is present only in the weak interactions via CKM mechanism **in the SM**, but **is too small** to explain the absence of antimatter in the universe

Possibly there are other sources of CPV beyond SM. Need to search for CPV effects extensively



[1] A. D. Sakharov, "Violation of CP invariance, C asymmetry, and baryon asymmetry of the universe," JETP Lett. 5, 24-27 (1967), Sov. Phys. Usp. 34, 392-393 (1991)

- b-baryon sector, relatively unexplored territory to search for CPV
- possible large interference between tree and penguin diagrams



- ✓ Potentially large CPV effects in charmless  $\Lambda_b^0$  decays, up to  $A_{CP}=20\%$
- Phys. Rev. D 91, 116007 (2015)

	Our result	pQCD [4]	Data
$10^2 \mathcal{A}_{CP}(\Lambda_b \rightarrow pK^-)$	$5.8 \pm 0.2 \pm 0.1$	$-5_{-5}^{+26}$	$-10 \pm 8 \pm 4$ [7]
$10^2 \mathcal{A}_{CP}(\Lambda_b \rightarrow p\pi^-)$	$-3.9 \pm 0.2 \pm 0.0$	$-31_{-1}^{+43}$	$6 \pm 7 \pm 3$ [7]
$10^2 \mathcal{A}_{CP}(\Lambda_b \rightarrow pK^{*-})$	$19.6 \pm 1.3 \pm 1.0$	...	...
$10^2 \mathcal{A}_{CP}(\Lambda_b \rightarrow p\rho^-)$	$-3.7 \pm 0.3 \pm 0.0$	...	...

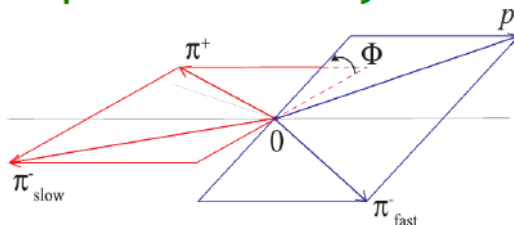
# CP Violation at LHCb - $\Lambda_b$ Decays



In the flavour sector, LHCb has a wealth of measurements, and is probing CP violation in new processes

First evidence for CP violation in  $\Lambda_b \rightarrow p\pi^-\pi^+\pi^-$

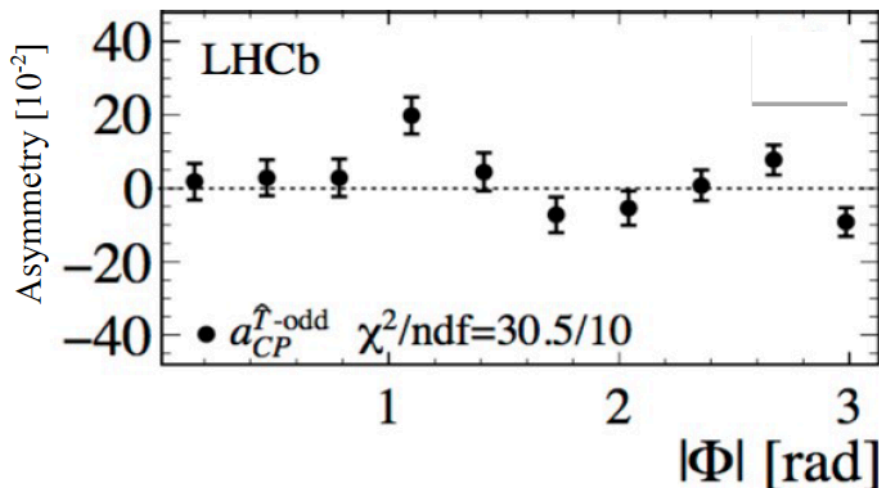
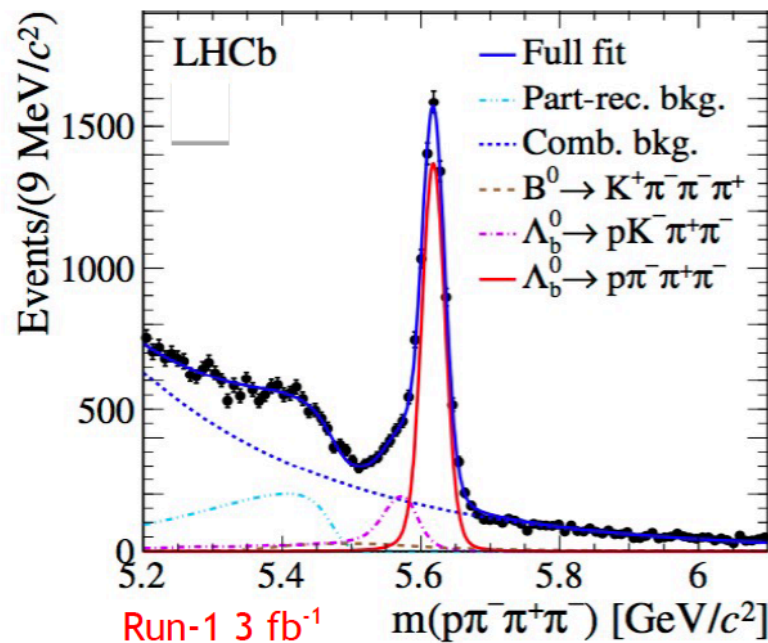
- Searching for local CP-violating effects in  $\Lambda_b \rightarrow p\pi^-\pi^+\pi^-$  decays as a function of the relative orientation between the decay planes formed by the  $p\pi^-$  and  $\pi^+\pi^-$  systems ( $\Phi$ )



- Evidence is found for CP violation at the  $3.3\sigma$  level

First evidence of CP violation in the baryon sector

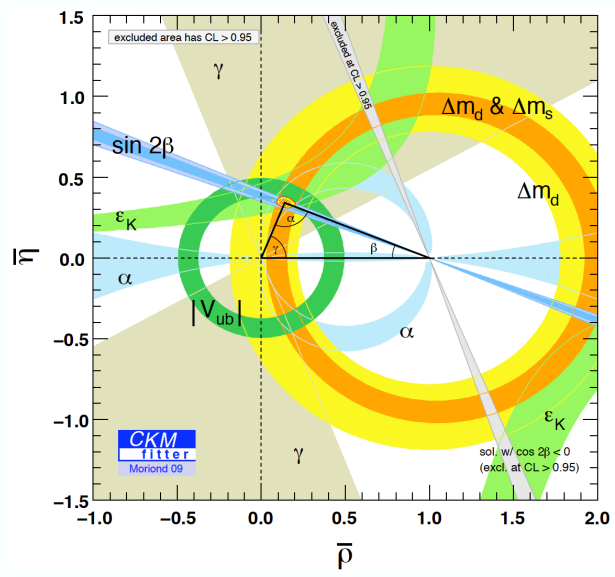
LHCb-PAPER-2016-030 in preparation



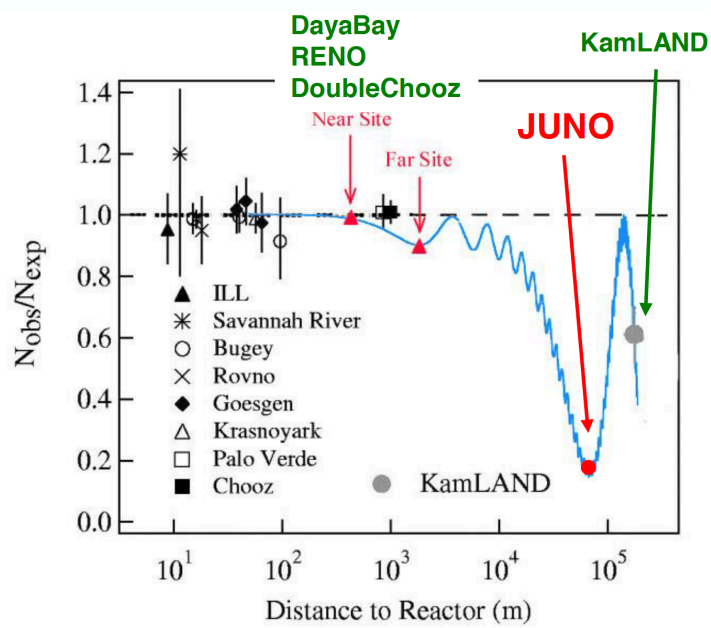
# Charged lepton: results and future prospects

Now we know that

Quarks mix



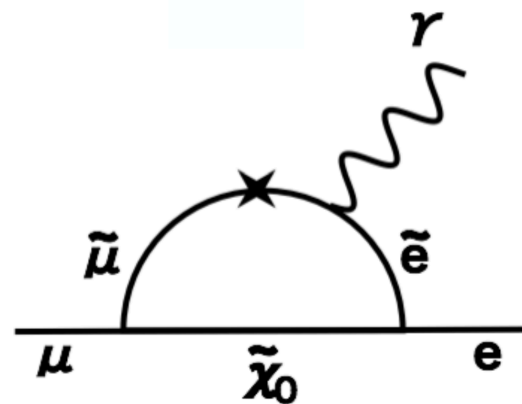
Neutrinos oscillate



How about charged leptons ?

# charged lepton flavor violation (cLFV)

- In the SM, the charged lepton flavor is conserved
  - cLFV have not been observed
  - cLFV in SM through  $\nu$ -oscillations is very tiny
- In many new theories beyond the SM (e.g. SUSY-GUT, SUSY-seesaw, extra-dimension...), the charged lepton flavor is naturally violated
  - Predicted branching ratios of cLFV rare decays are sizable !!
- Any observations of cLFV will be unambiguous evidences of new physics (NP)
- Complementary to direct searches at LHC
  - Sensitive to higher NP masses
  - color-less new particles are not constrained very much



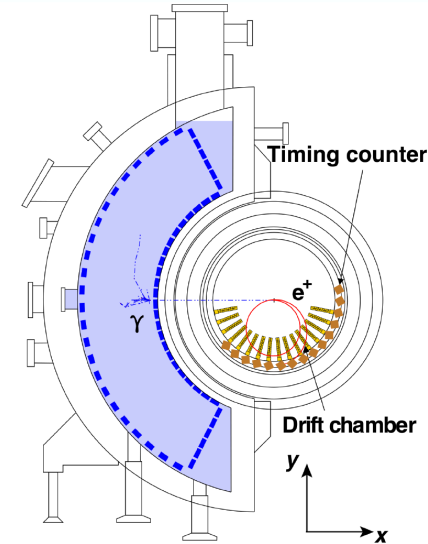
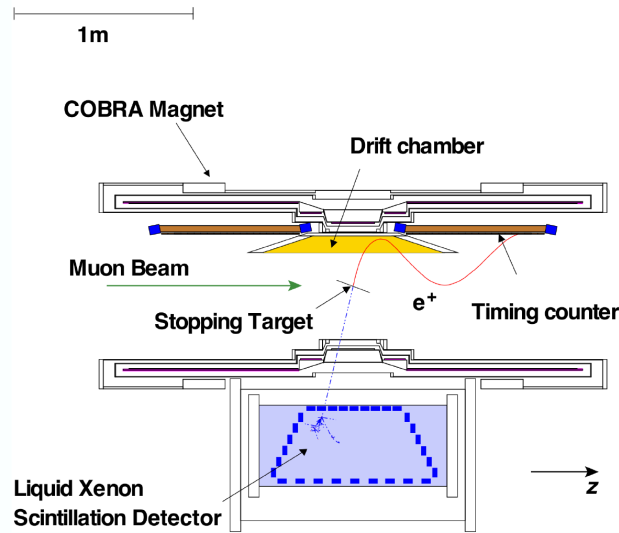


# Hints of new physics in charged lepton sector

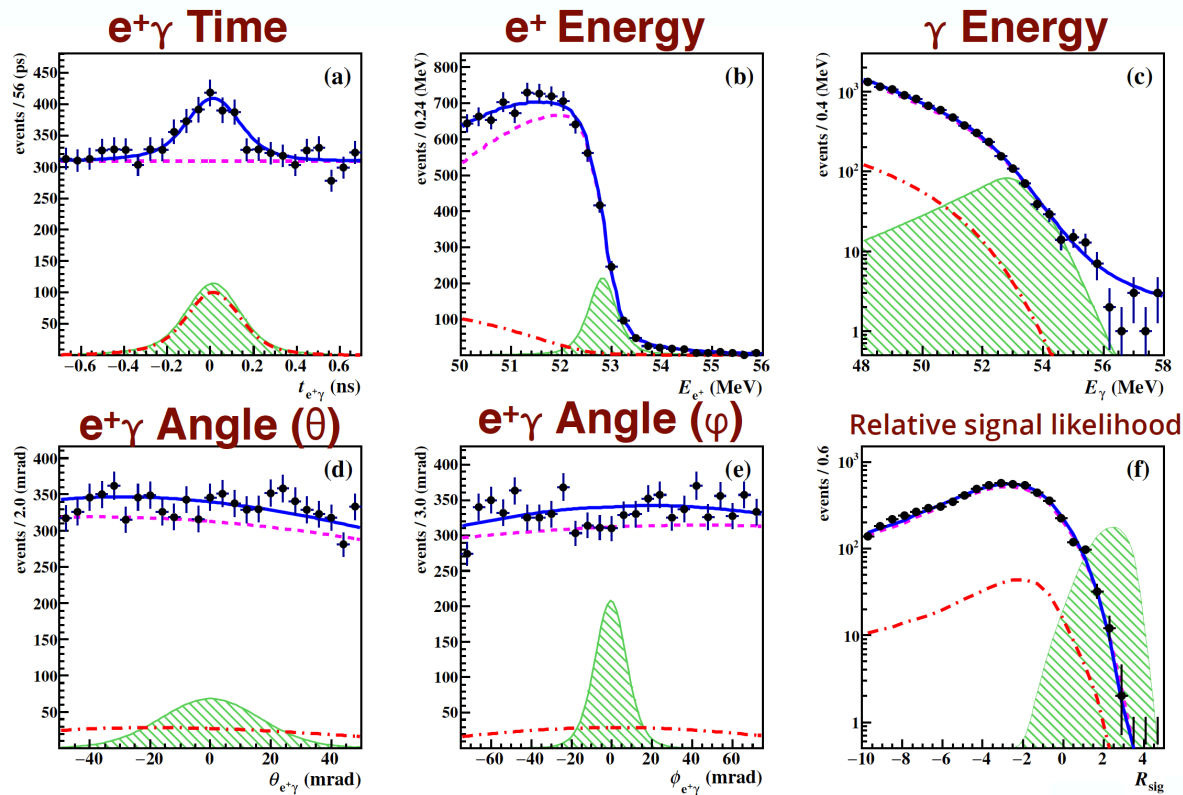
- Muon  $g-2$  :  $3.6 \sigma$  difference from the SM value (BNL E821)
  - Next generation experiments at Fermilab (first result in FY2017—2018) and J-PARC
- Proton radius puzzle :  $7 \sigma$  difference between  $ep$  and  $\mu p$  (CREMA@PSI)
  - $e-\mu$  universality violation ?
  - New results expected from CREMA, MUSE, PRad, MAMI
- B-physics
  - $B \rightarrow D\tau\nu$  vs  $B \rightarrow D\mu\nu$  :  $3.9 \sigma$  difference from SM
  - $b \rightarrow s$  flavor anomalies
    - $BR(B^+ \rightarrow K^+\mu\mu) / BR(B^+ \rightarrow K^+ee)$ ,  $BR(B_s \rightarrow \phi\mu\mu)$ ,  $B \rightarrow K^*\phi\mu\mu$  angular analysis
- $H \rightarrow \mu\tau$ : CMS observed with  $2.4 \sigma$  significance in Run 1 data

# $\mu \rightarrow e \gamma$ : MEG

- Searching for cLFV decay  $\mu^+ \rightarrow e^+ \gamma$
  - Most intense DC  $\mu^+$  beam,  $3 \times 10^7 \mu/\text{sec}$  @ PSI, Switzerland
  - Detector
    - Photon : Largest LXe photon detector
    - Positron : gradient B-field, Ultra light drift chamber, high resolution  $e^+$  timing counter
  - Data taking in 2008-2013
  - Previous result with 2009-2011 dataset
    - Br UL :  $5.7 \times 10^{-13}$  (90%CL)
- PRL, 110 201801 (2013)*
- Analysis of full data completed



# MEG : Fit on the full data



Accidental BG  
RMD  
100x signal upper limit

→  
signal-like

Data consistent with BG PDF

# Final result of MEG

No excess was found and the new UL was set

$$\mathcal{B}(\mu^+ \rightarrow e^+ \gamma) < 4.2 \times 10^{-13} @ 90\% \text{ C.L.}$$

arXiv:1605.05081  
ready for publication from EPJC

**x30 more stringent than the previous experiment**

( $\times 10^{-13}$ )	2009-2011 data	2012-2013 data	All combined
<b>Best Fit</b>	-1.3	-5.5	-2.2
<b>90% CL Upper limit</b>	6.1	7.9	<b>4.2</b>
<b>Sensitivity</b>	8.0	8.2	<b>5.3</b>

Previous limit with 2009-2011 dataset :  $5.7 \times 10^{-13}$   
UL : Feldman-cousins with profile-likelihood ratio ordering

Systematic uncertainties

UL increase by

- 5% by target position/shape uncertainties
- <1% by other systematic uncertainties

# Future : MEG II

Upgrades for 10 times higher sensitivity

Liquid Xenon Gamma-ray Detector

COBRA  
Superconducting  
Magnet

Gamma ray

VUV sensitive SiPMs  
~4000 SiPM in the detector

Beam intensity >2 higher than MEG I

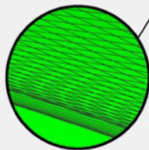
Single volume, stereo  
wire chamber

Drift Chamber

Newly added e<sup>+</sup>  
detector for BG veto

Muon

Positron



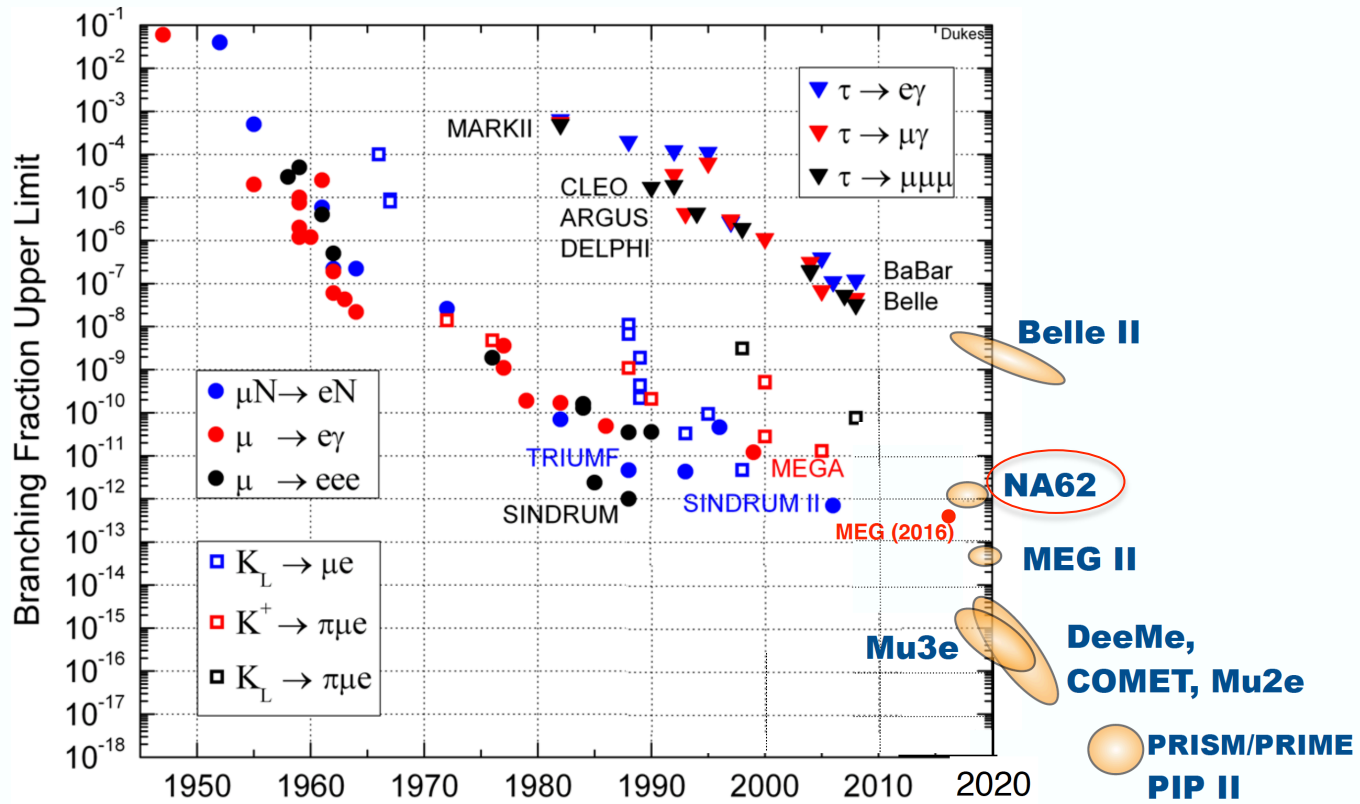
Positron Timing Counter

Radiative Decay Counter

highly segmented plastic counters



# Prospects



# Some other topics

- Gravitational waves
  - 4 talks and public lecture
  - Widely presented in Birmingham
- Neutrino physics
  - See Birmingham seminars over last couple of years (and last week)

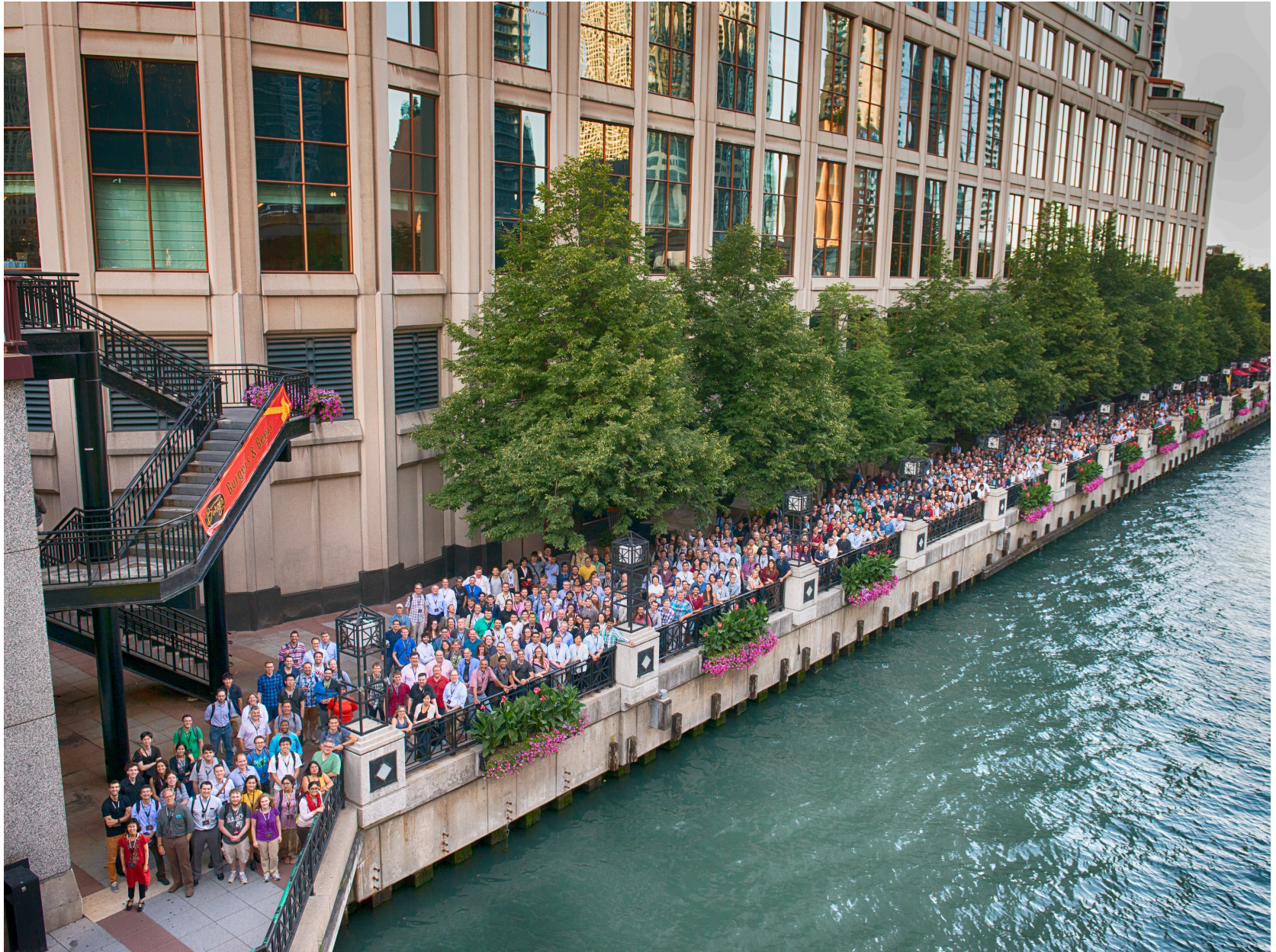
- 
- Many new results have been released from the accelerator experiments this summer:
    - NOvA observes hints of non maximal mixing.
    - T2K does not find evidence of CPT.
    - T2K excludes CP conservation at 90%.
    - NOvA excludes a CP region of inverted hierarchy for the lower octant.

Mayly Sanchez - ISU

- Dark matter and dark energy
  - On last (extended) afternoon
  - Please look at the slides:  
<http://indico.cern.ch/event/432527/timetable/>



# The official conference photo!





# 2017: Lepton Photon in Guangzhou (China)

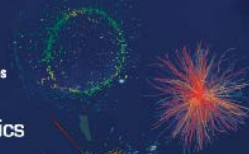


# 2017: EPS-HEP (Venice)



Information - Events - Committees

International High Energy Physics  
15-12 July 2017



# 2018: ICHEP in Seoul (Korea)

# ICHEP2018 SEOUL

## 39<sup>TH</sup> INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

JULY 4-11, 2018

SEOUL



# Future ICHEP and Lepton conferences

- Lepton Photon 2019:  
✓ Toronto (Canada)
- ICHEP 2020:  
✓ Prague (Czech Republic)

