38th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

AUGUST 3 - 10, 2016
CHICAGO

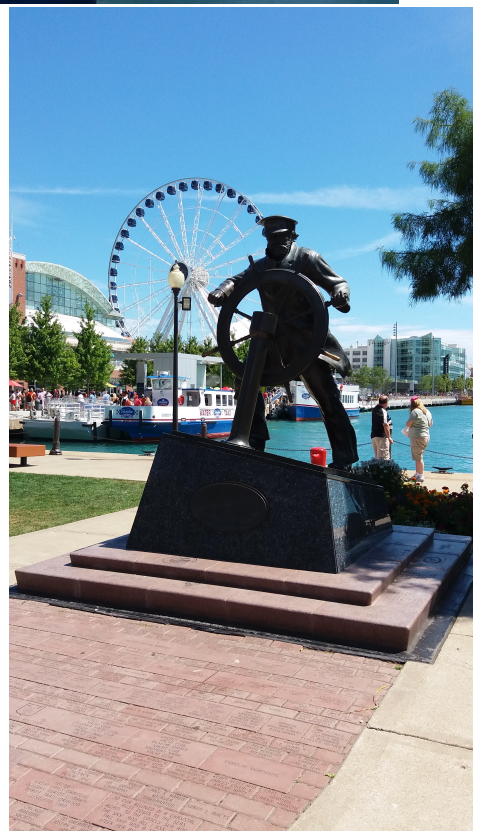
Miriam Watson
University of Birmingham

A few highlights, biased towards my interests

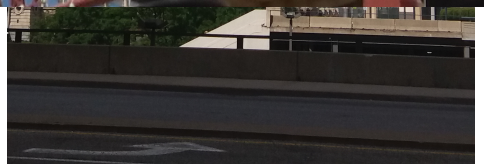
Slides mostly taken from plenary review talks
(but there were no theory/experimental summaries)

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

The local area….




TRUMP



Conference timetable

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

Morning

Afternoon

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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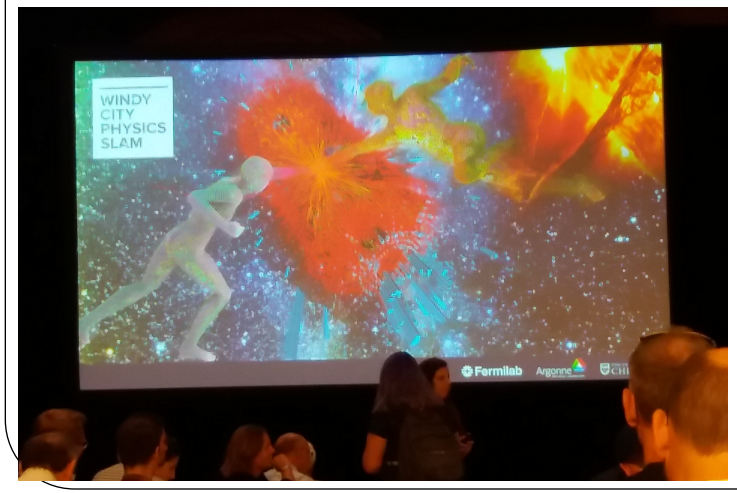


- Windy City Physics Slam

- ICHEP Zumba!

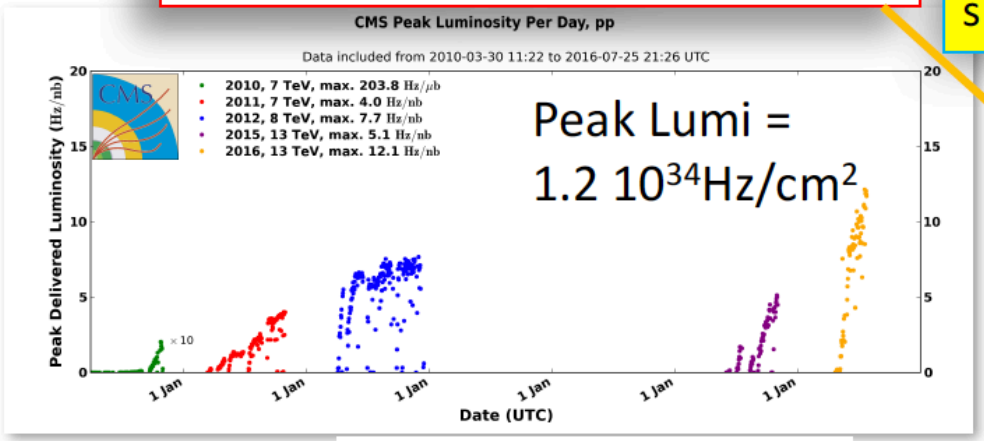
LHC results: Standard Model and searches

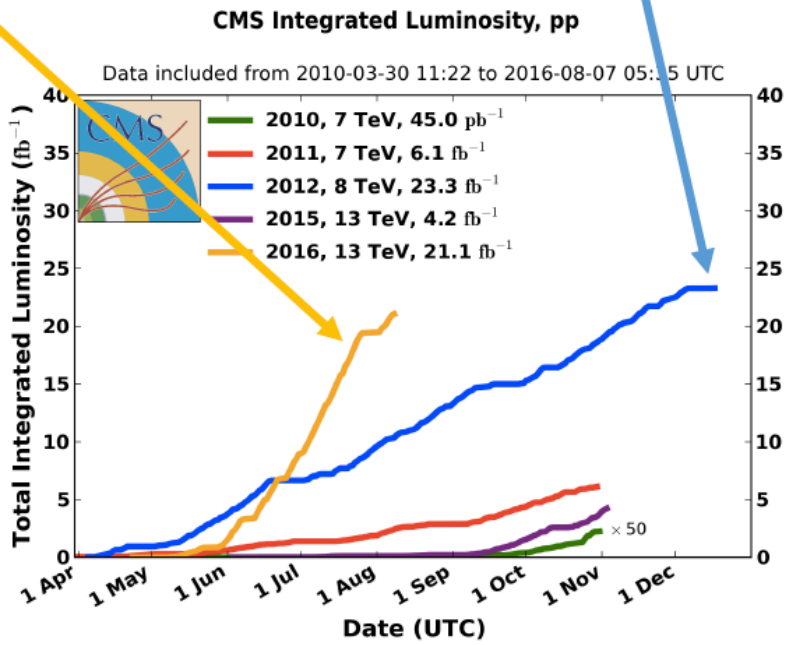
LHC: a superb performance

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

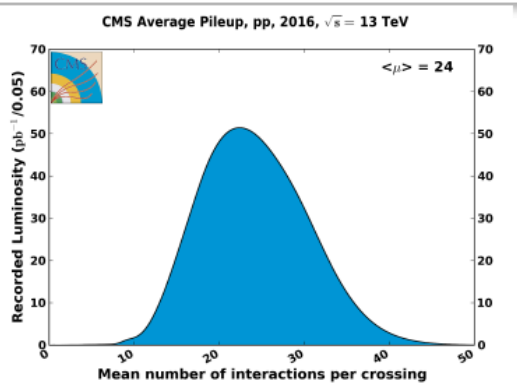
Luminosity used for the results presented today 12.9 fb^{-1}

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





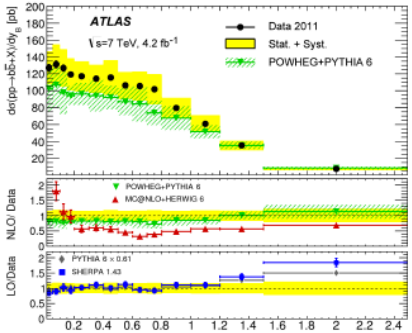
Pileup distribution for the data shown here

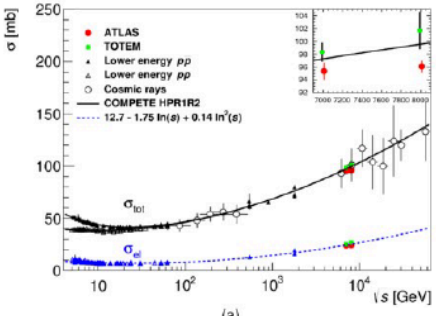


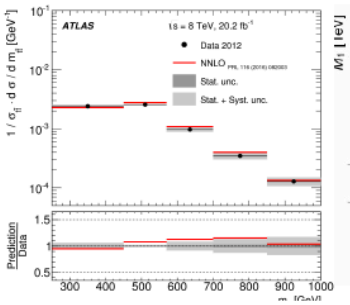
CMS livetime ~95% and > 94% of logged data usable for any physics analysis

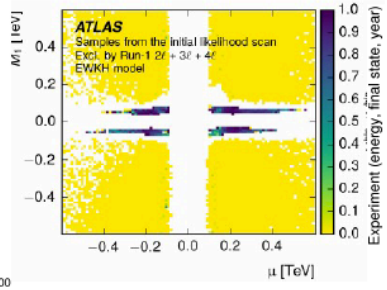
A Small Selection

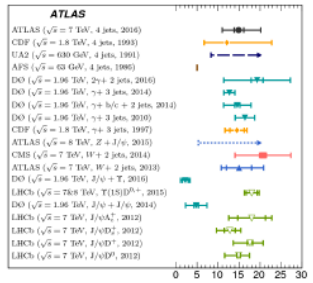
In total **64** new results prepared for ICHEP, **56** using 13 TeV data and **45** with 2015+2016
ATLAS has now submitted **40** papers with Run-2 data (**576** total with collision data)
The flood-tide of Run-1 results has not yet ebbed

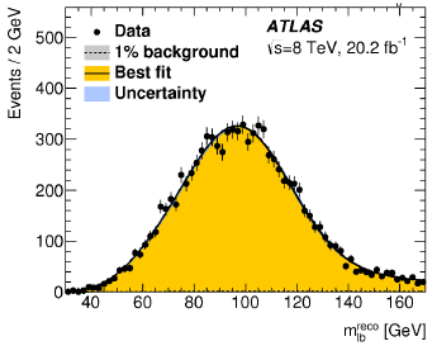


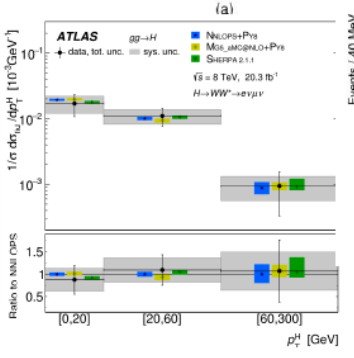


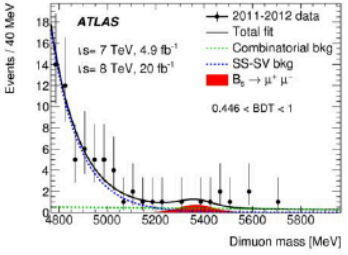


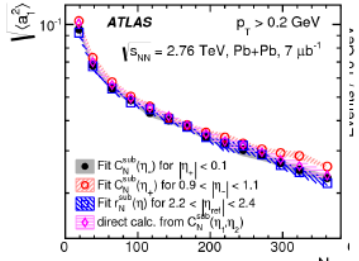


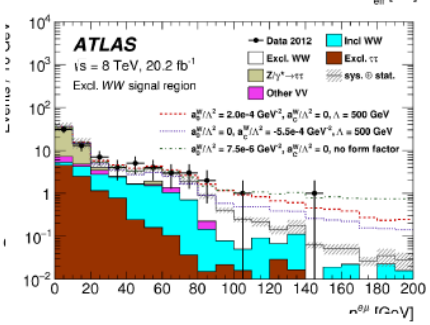


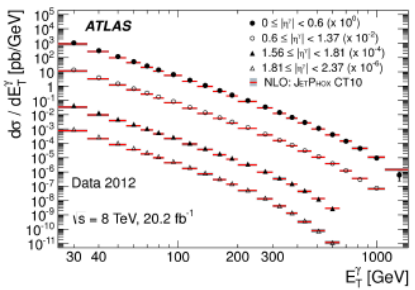


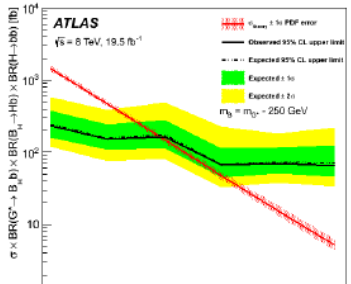


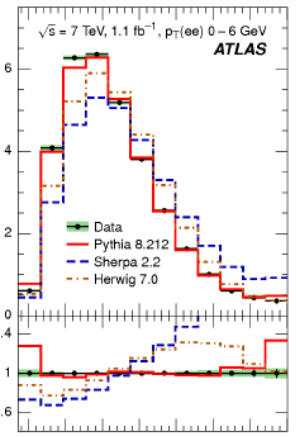


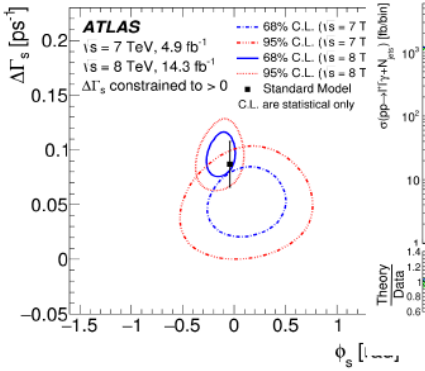


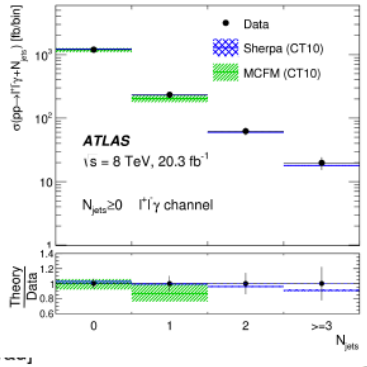












Search for a high mass diphoton resonance using the ATLAS detector

Bruno Lenzi (CERN)
on behalf of the ATLAS collaboration

Parallel session talks

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

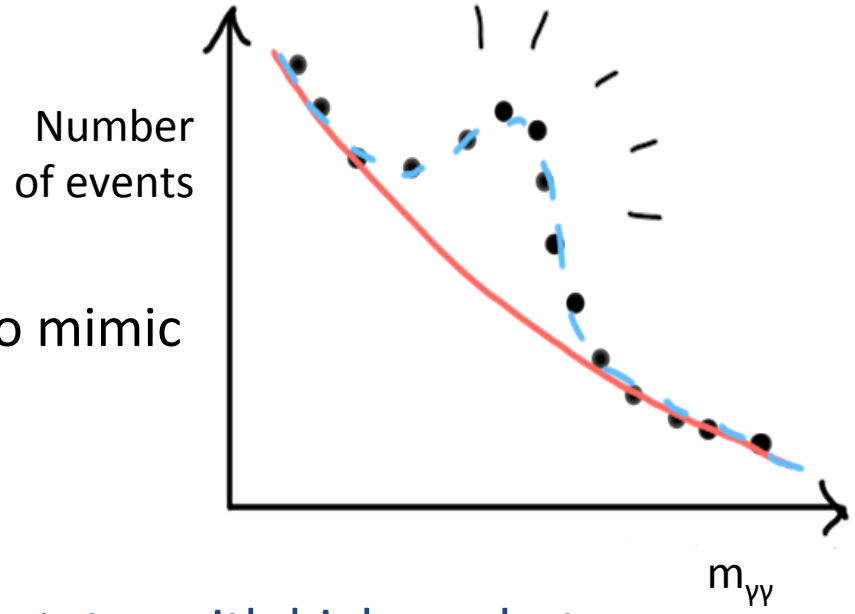
Why di-photon searches

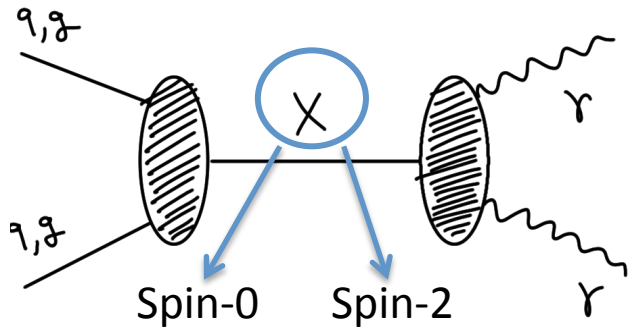
Fully reconstructed resonances: simplest way to discover new particles

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

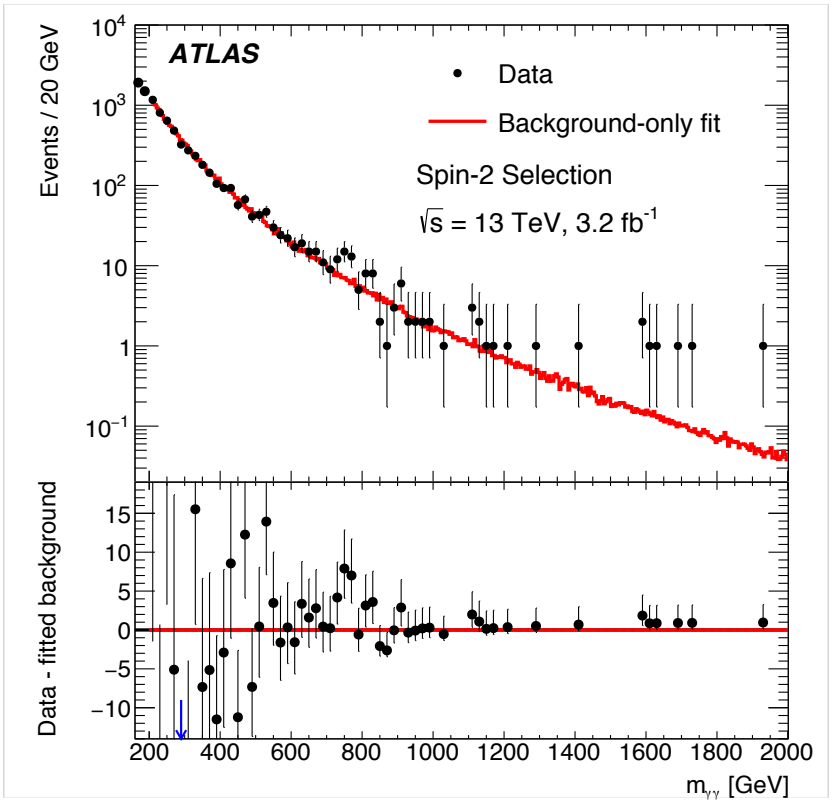
Introduction

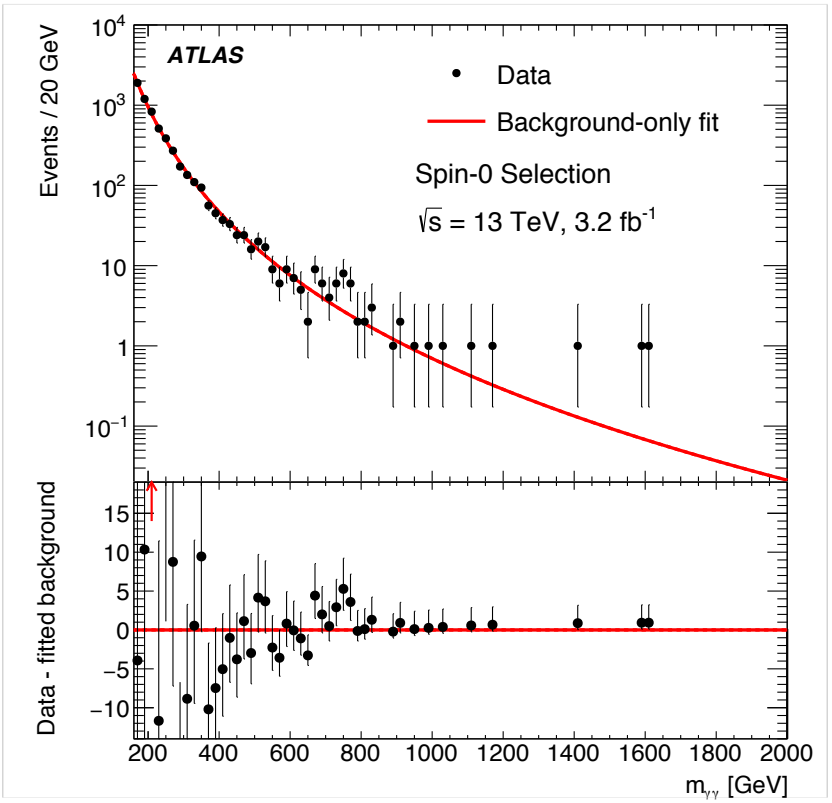
- Resonances decaying to diphotons predicted by several BSM models
- Search for peak (width ~ few %) over smoothly falling background

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

- Results with 2015 data (3.2 fb^{-1}), submitted to JHEP (arxiv:1606.03833)
- New results with 15.4 fb^{-1} of reprocessed 2015 data + 2016 data presented for the first time (ATLAS-CONF-2016-059)

Results from 2015 data (arxiv:1606.03833)

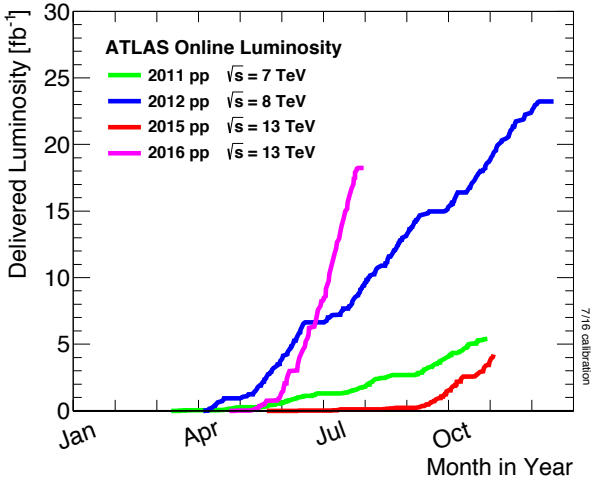




Broad excesses around $m_{\gamma\gamma}$ = 750 GeV

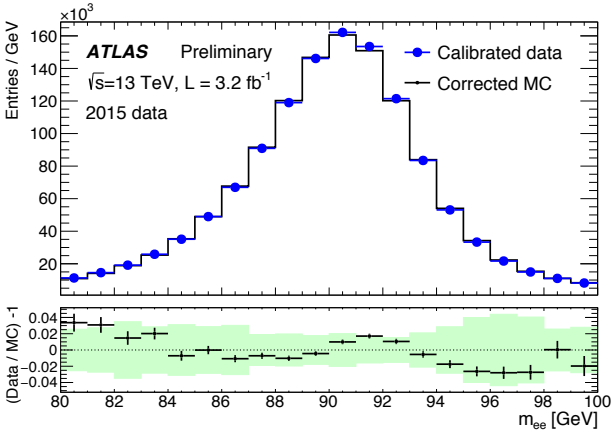
Since then…

- Impressive performance of the LHC
  - Peak luminosity beyond design
  - ATLAS data-taking efficiency > 90%
  - 12.2 fb^{-1} of 2016 data analysed
    - Data taken until July 16 (< 3 weeks ago!)

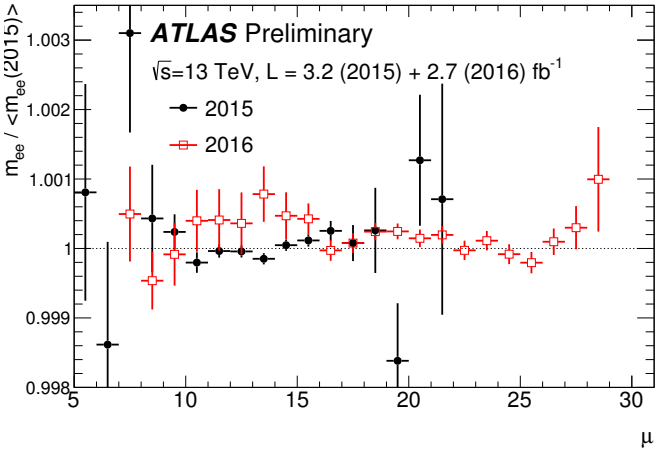


- Improved reconstruction and energy calibration, based on experience with 13 TeV data

Inv. mass (m_{ee}) from Z decays



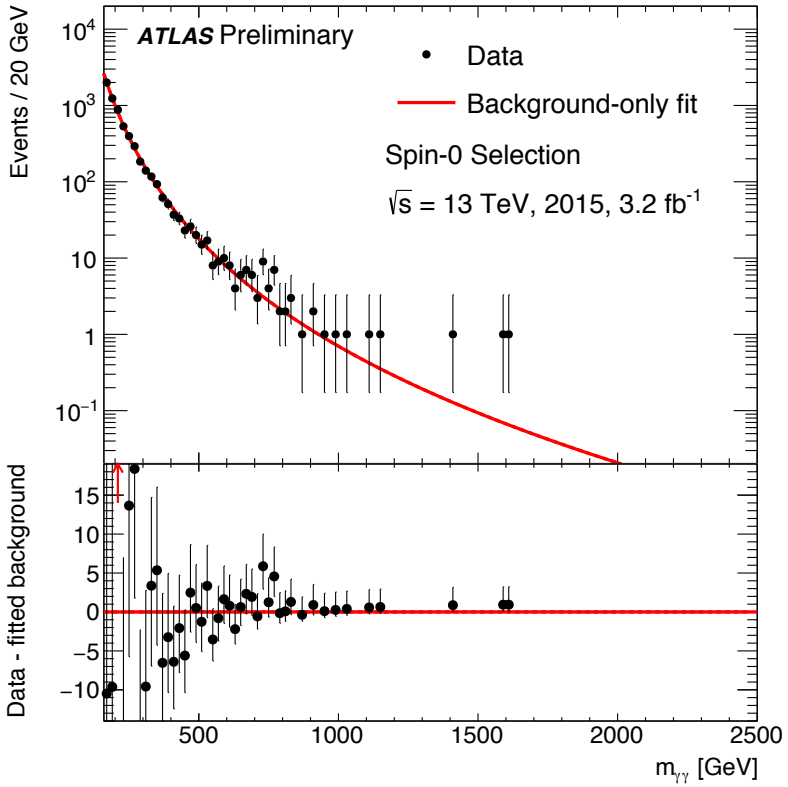
Stability of m_{ee} vs. pileup



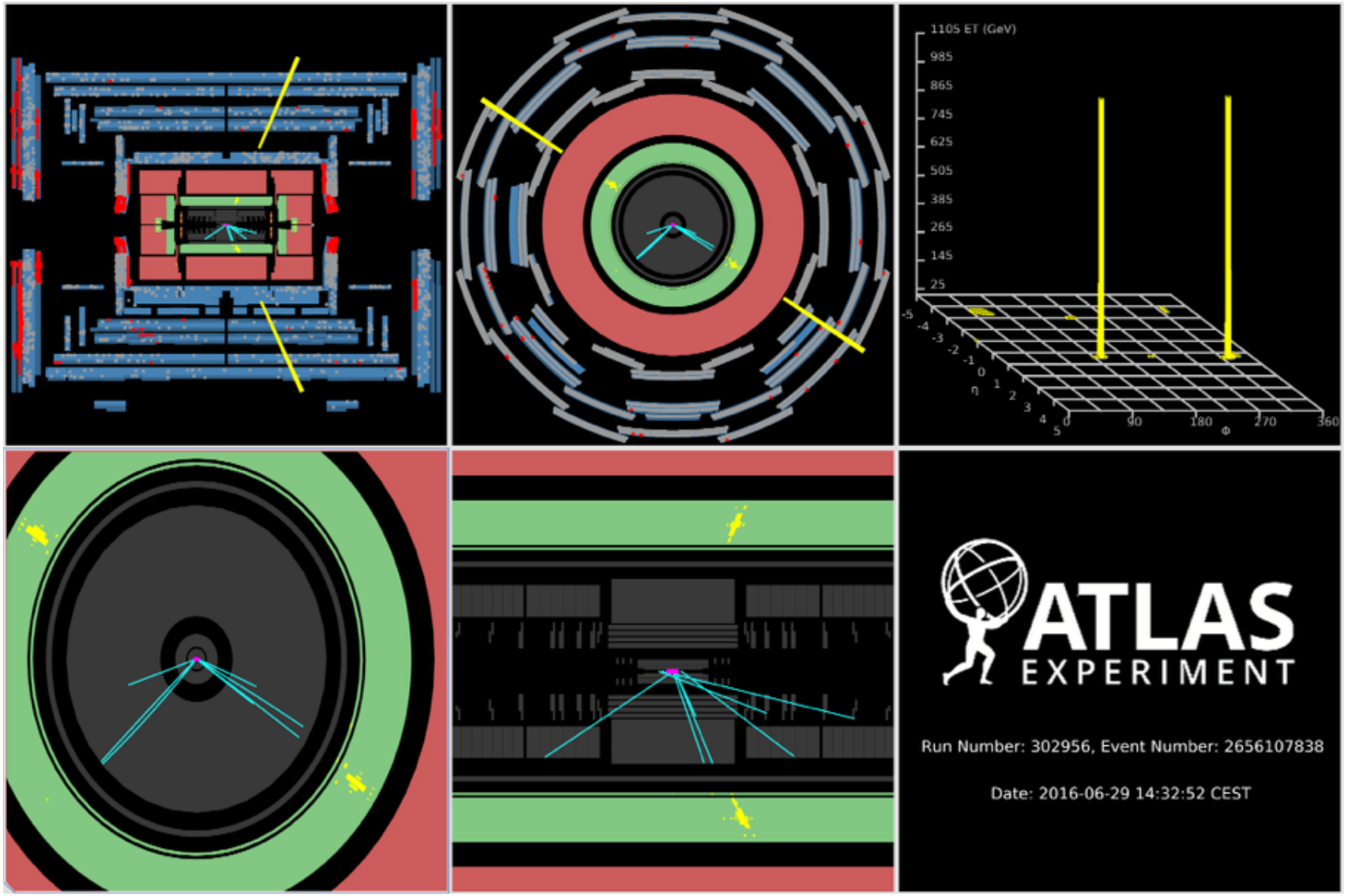
The "new" 2015 data: spin-0 analysis

- 2015 reprocessed and reanalysed
  - Excess @ 750 GeV → 730 GeV
  - 3.9σ → 3.4σ 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

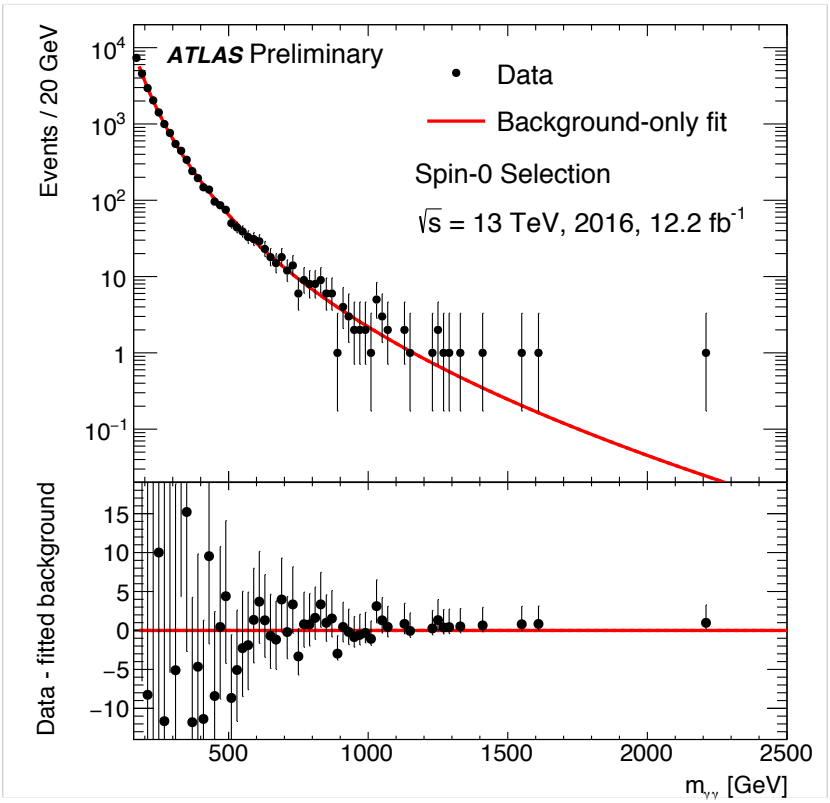


A diphoton candidate with $m_{\gamma\gamma}$ = 2.2 TeV

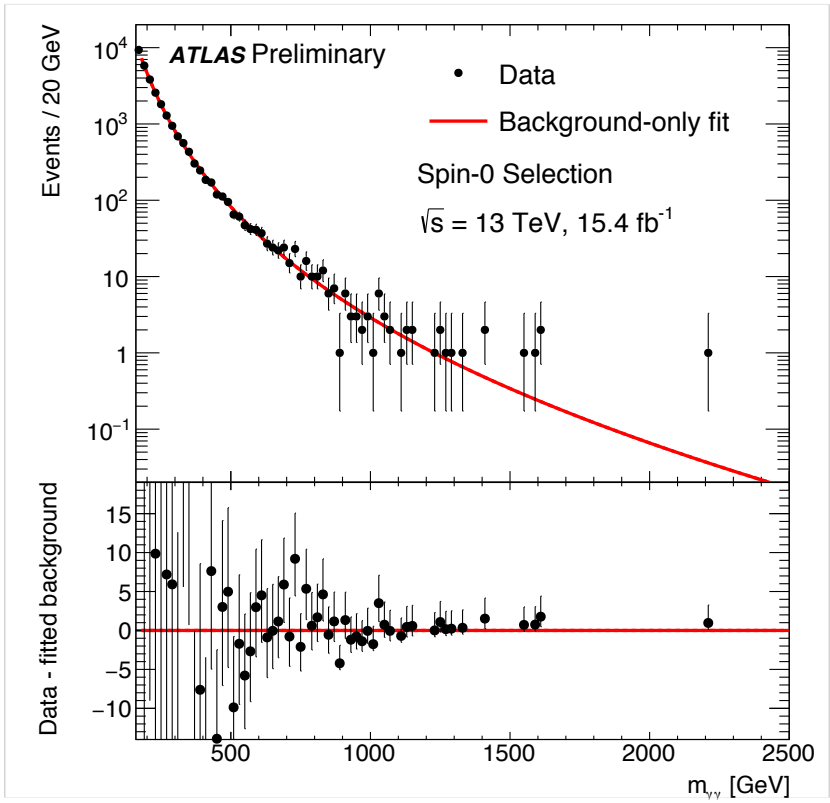


Spectra for 2016-only and 2015 + 2016 data

2016-only



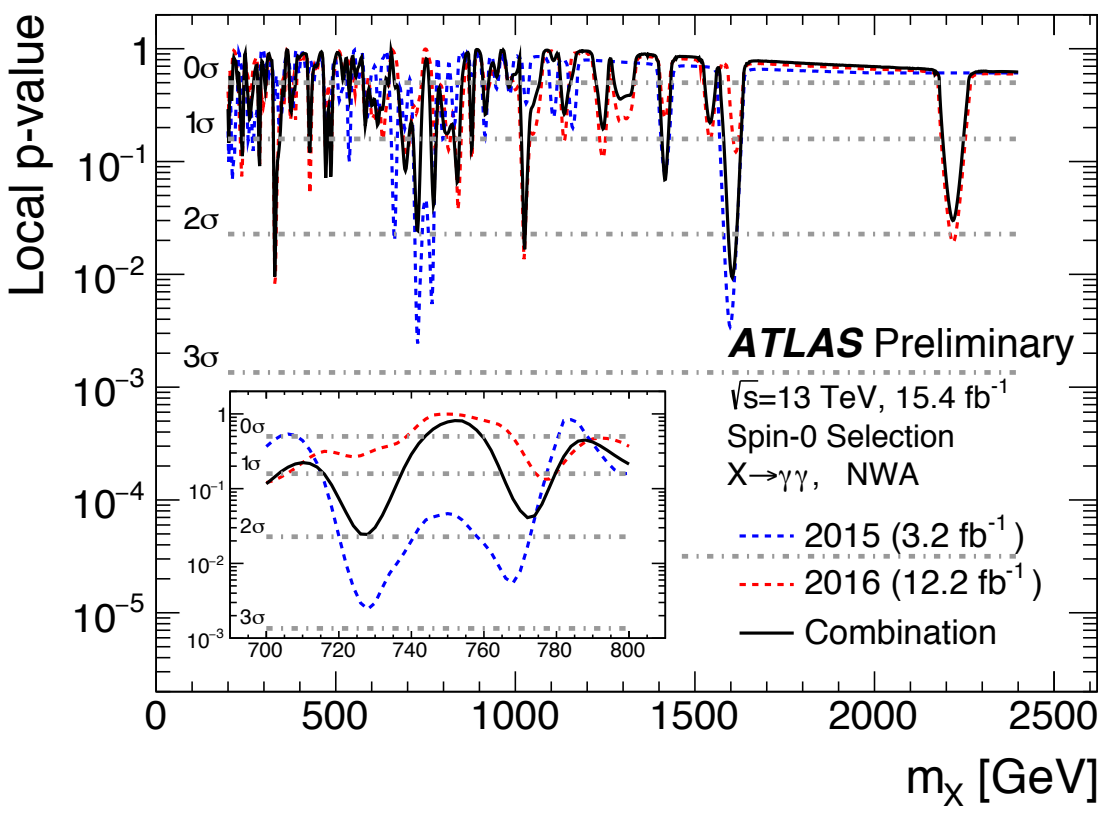
2015 + 2016



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

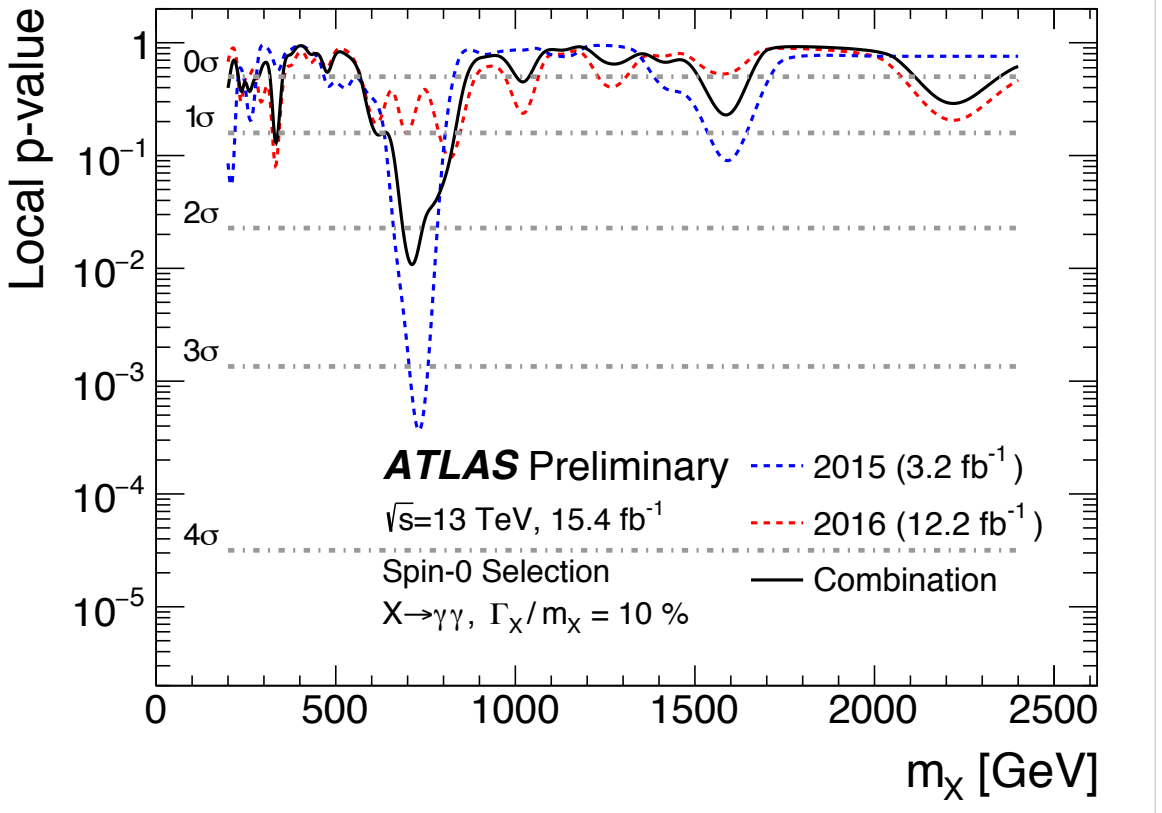
New results: significances for narrow-width signal

Largest significance for combined dataset @ 1.6 TeV (2.4σ local)



New results: significances for wide signal (10%)

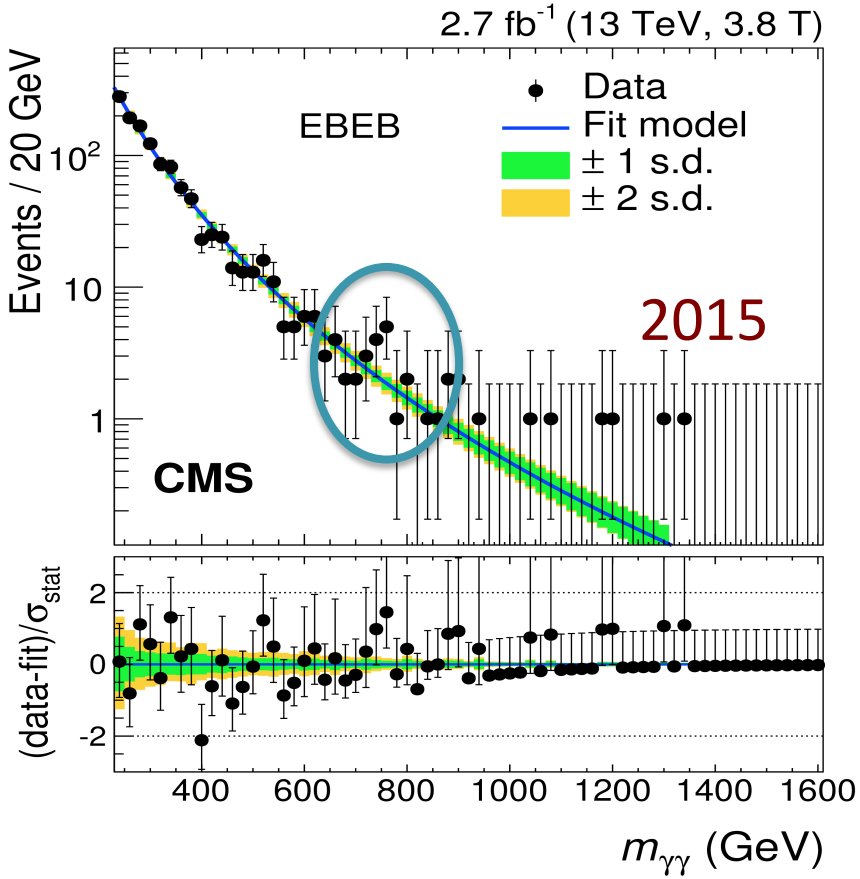
Around 700-800 GeV: 2.3σ local significance @ 710 GeV for combined dataset

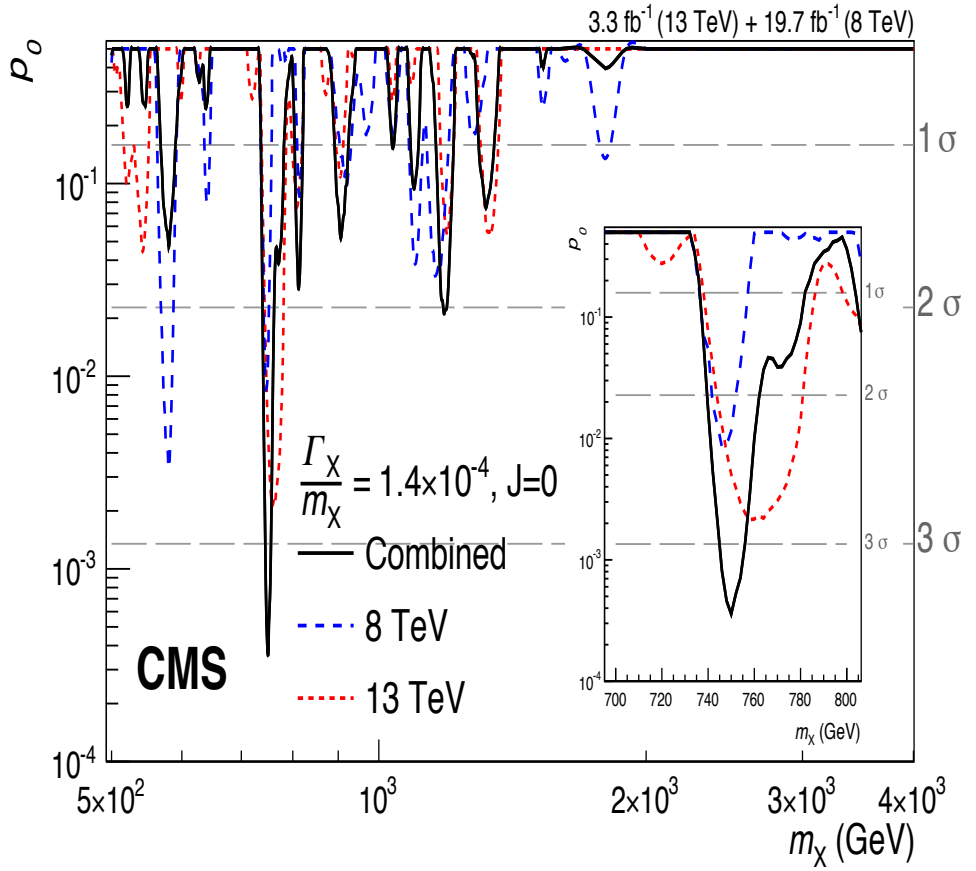


Recap of 2015 results

C.Rovelli

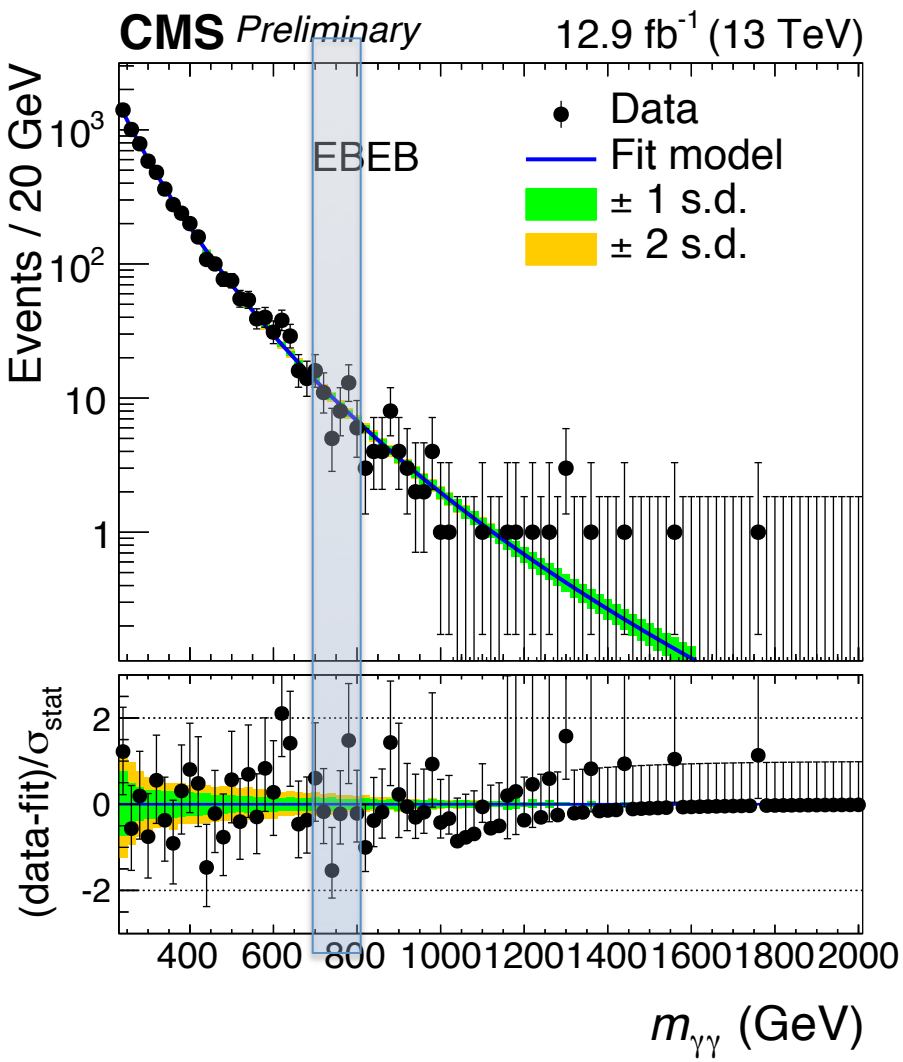
Phys.Rev.Let. 117(2016), no. 5, 051802

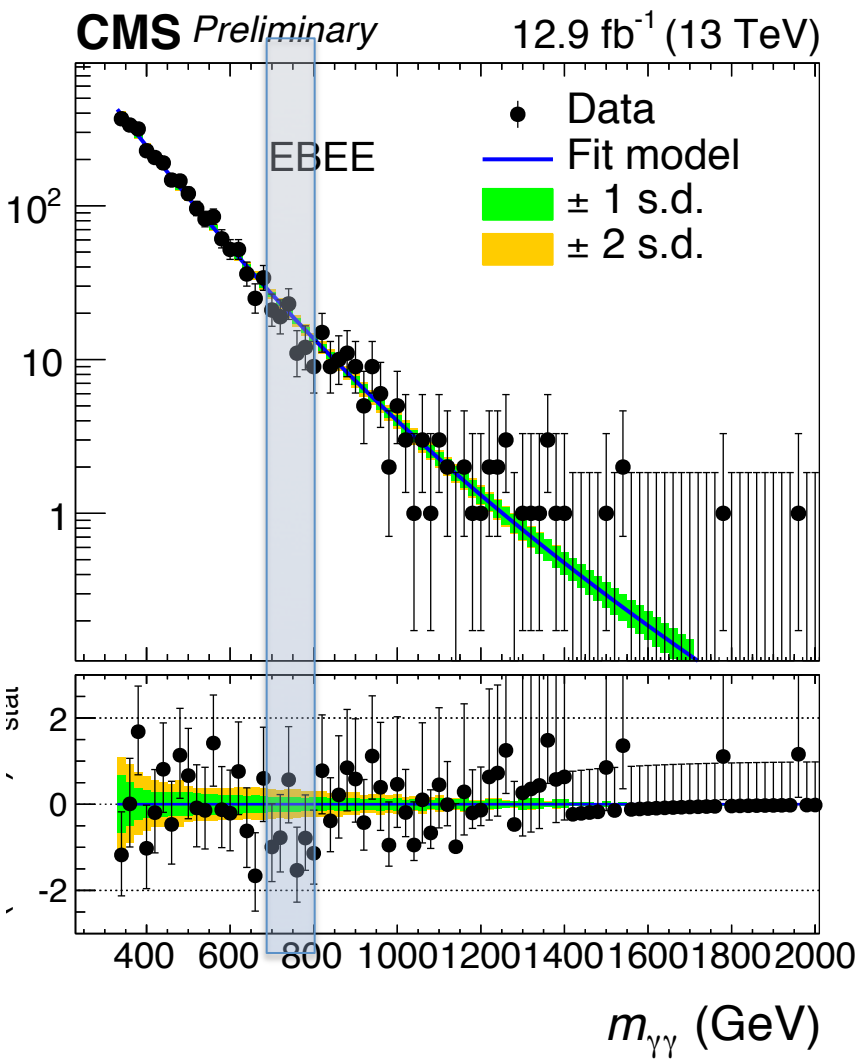




	2015	2015 + 8TeV
Mass (GeV)	760	750
Local significance	2.9σ	3.4σ
Global significance	<1σ	1.6σ

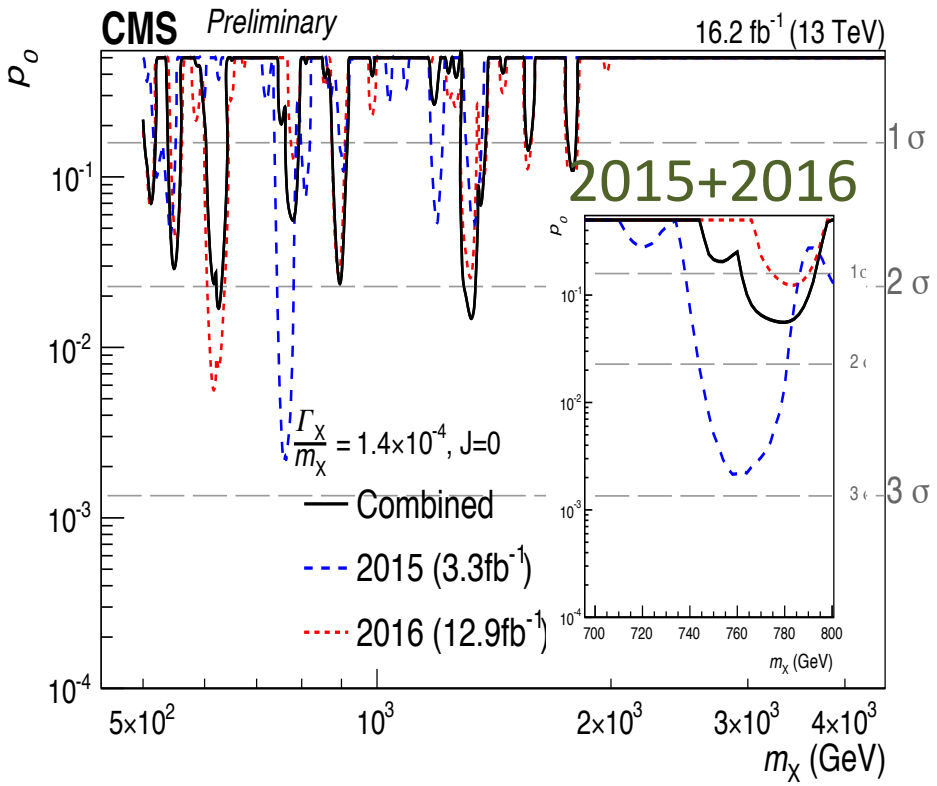
2016 mass spectra

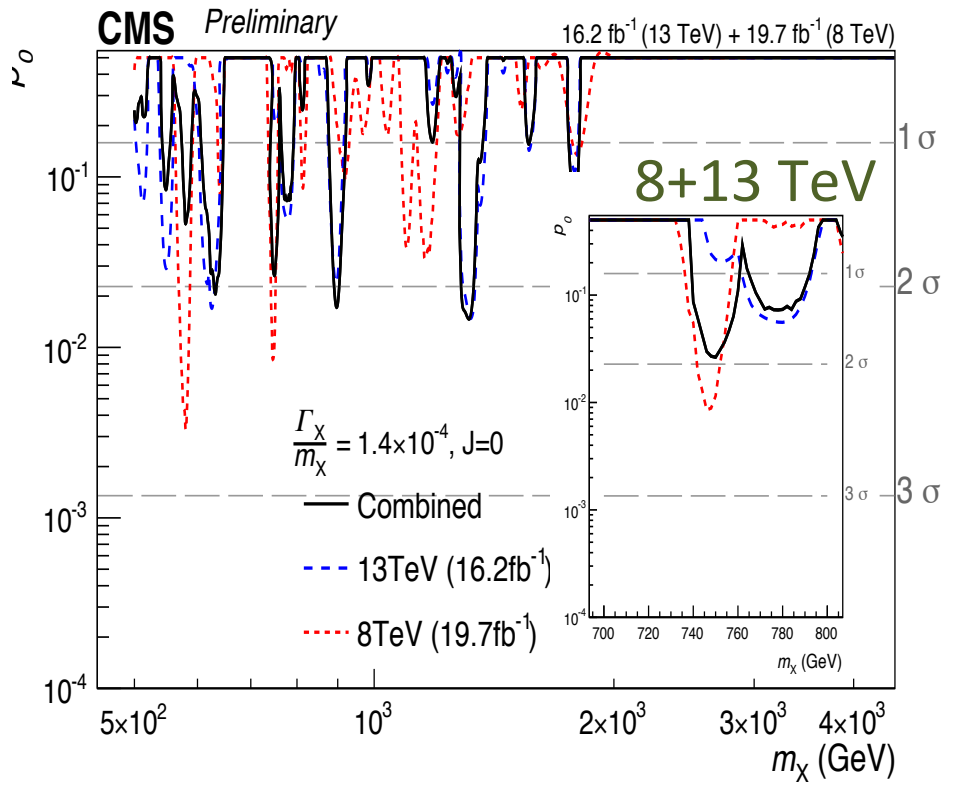




Data consistent with Standard Model expectations

Run1+Run2 significance





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

Local excesses around 750GeV:

2015 only: 2.9σ ⟶ 2015+2016: <1σ

8TeV+2015: 3.4σ ⟶ 8TeV+2015+2016: <2σ

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 2.4σ

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 1σ
  - 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

Fri 05/08

Print | PDF | Full screen | Detailed view | Filter

09:00

Search for a high mass diphoton resonance using the ATLAS detector (15' + 5') — *Bruno Lenzi*
Chicago 7 — 09:00 - 09:20

Searches for BSM physics in diphoton final state at CMS (15' + 5') — *Chiara Ilaria Rovelli*
Chicago 7 — 09:20 - 09:40

The Relaxion and Composite Higgs (12' + 3') — *Michael Fedderke et al.*
Chicago 7 — 09:40 - 09:55

10:00

Dark sector shining through 750 GeV dark Higgs boson at the LHC (12' + 3') — *pyungwon ko et al.*
Chicago 7 — 09:55 - 10:10

The NMSSM lives - with the 750 GeV diphoton excess (12' + 3') — *Krzysztof Rolbiecki et al.*
Chicago 7 — 10:10 - 10:25

Measuring the diphoton coupling of a 750 GeV resonance at the LHC (12' + 3') — *Christophe Royon et al.*
Chicago 7 — 10:25 - 10:40

Diphoton and Diquark Resonances in U(1) Extension of MSSM (12' + 3') — *qaisar shafi*
Chicago 7 — 10:40 - 10:55

11:00

Higgs-radion Interpretation of the 750 GeV di-photon excess at the LHC (12' + 3') — *Jack Gunion*
Chicago 7 — 10:55 - 11:10

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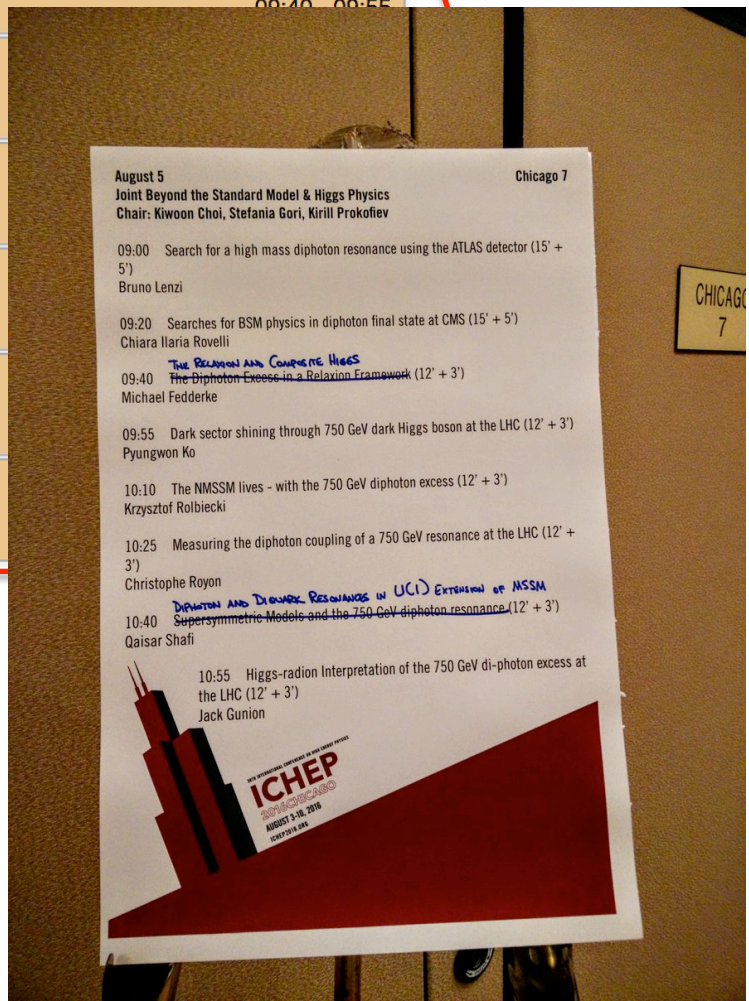


Some hasty editing….

The NMSSM lives
(with or without a diphoton excess)

or not ....

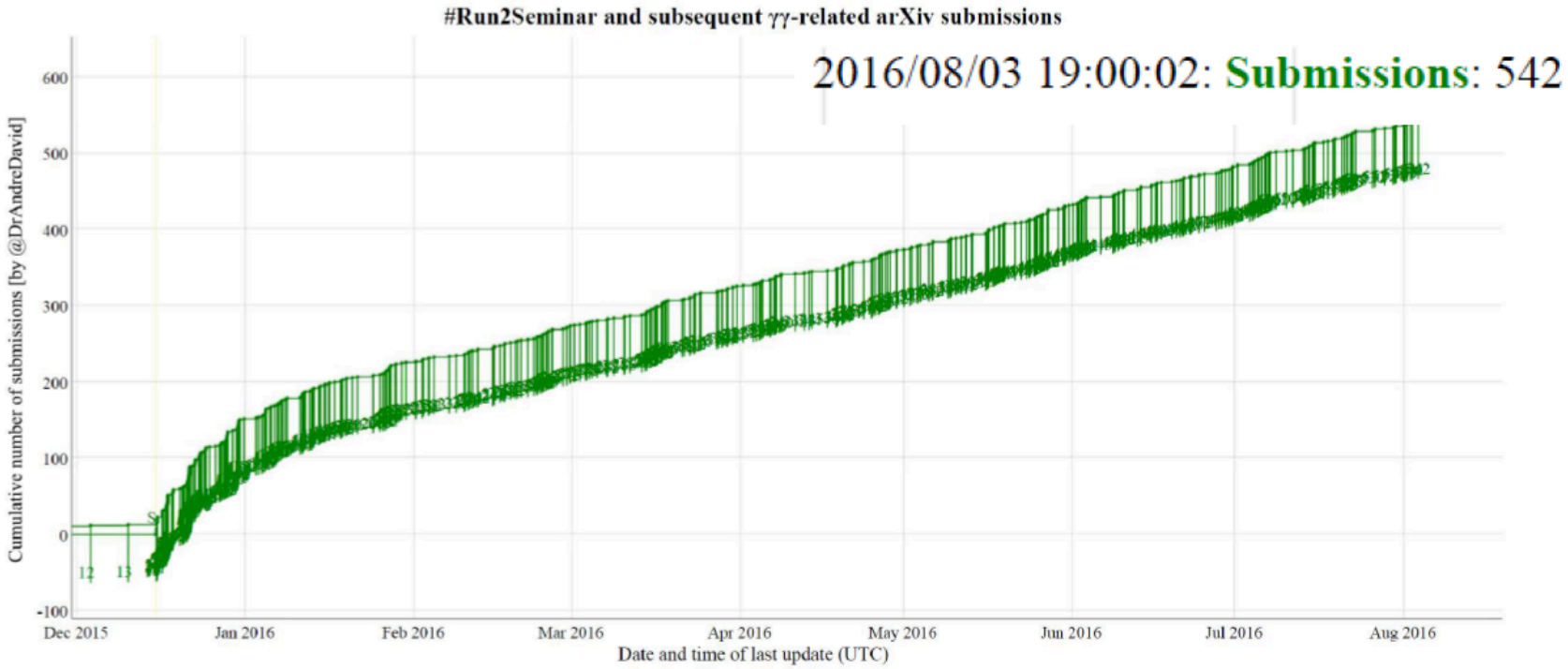
My own related works

- 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,

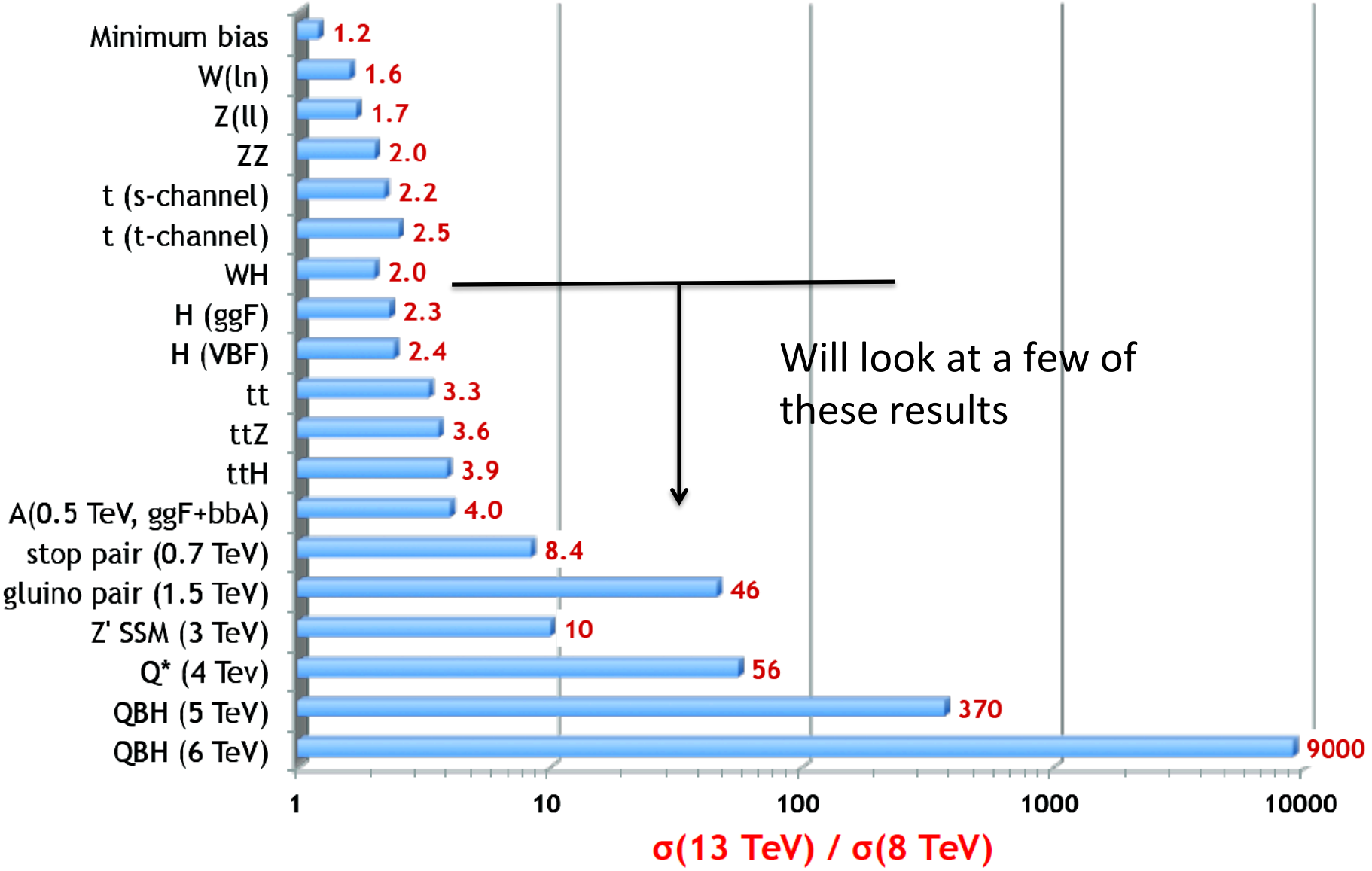
Near threshold behavior of heavy particle loops,

Resonance-continuum interference,

Single photon vs diphoton-jet,

.....

Cross-section Increase 8→13 TeV



Top pair cross section overview

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

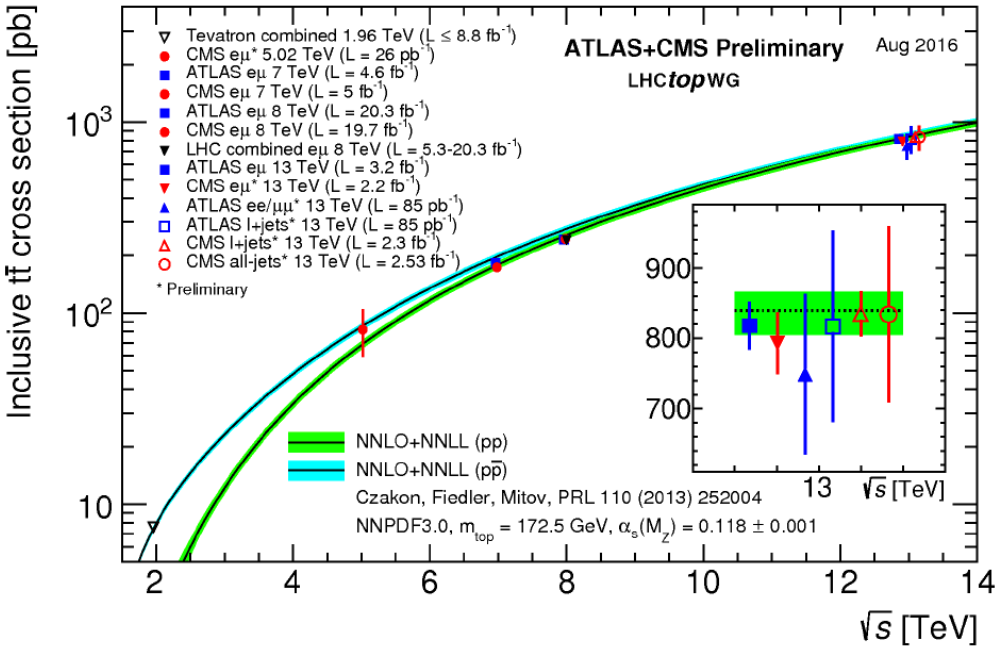
..most recent:

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

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

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

CMS, 26pb^{-1},5TeV, 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 ±(3.9-4.4)% (7-13 TeV) betters NNLO+NNLL predictions (~5%)

High tt̄ statistics → detailed studies of production properties

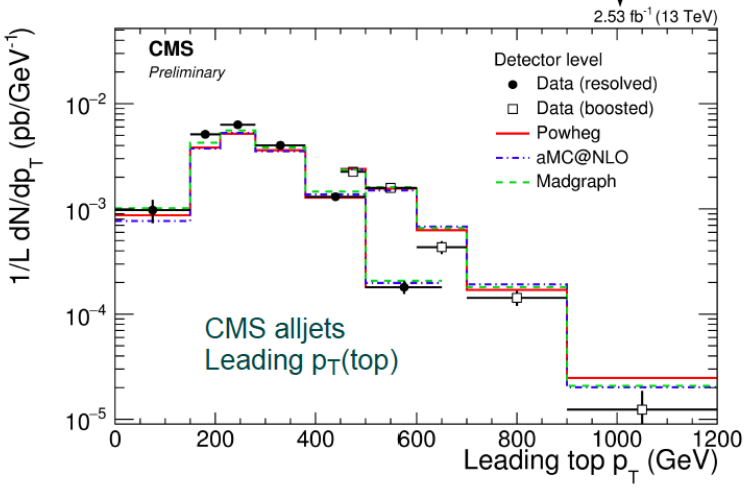
D Charlton

Top @ 13TeV: Going differential

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

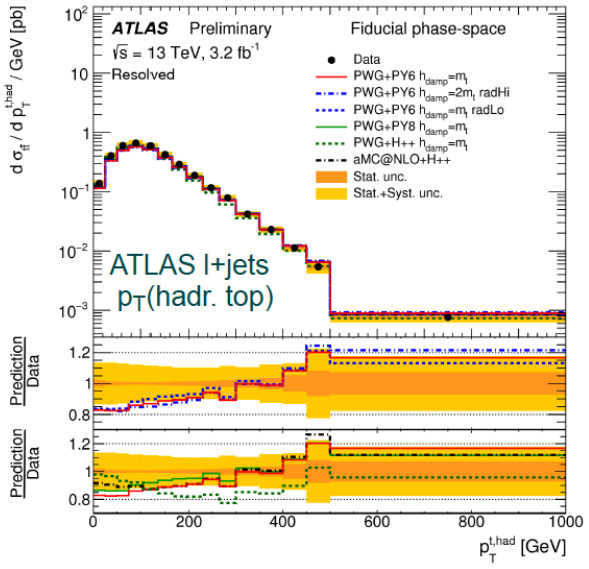
CMS, 2.2fb^{-1},13TeV, dilep, differential p_T(t), y(t), y(tt),m(tt),ΔΦ(tt), CMS-PAS-TOP-16-007

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

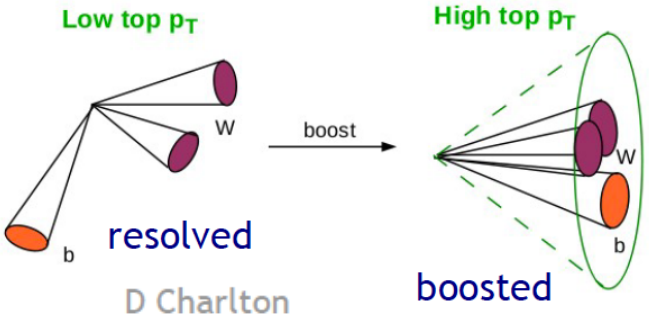


CMS, 2.3fb^{-1},13TeV, dilep, ttbb, ttjj
CMS-PAS-TOP-16-010

ATLAS, 3.2fb^{-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)

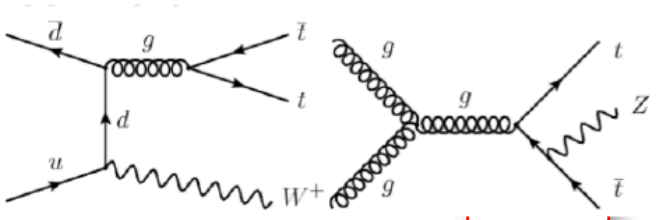


Many more results available at Top 2016:
https://indico.cern.ch/event/486433/overview

Top pairs + W/Z

σ(13 TeV)/σ(8 TeV)~3.6

TOP-16-017



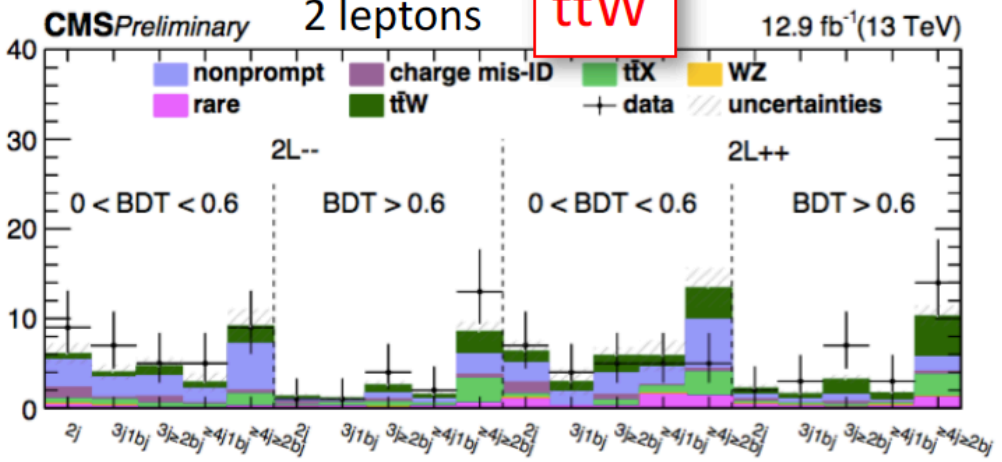
Select event with 2 SameSign leptons(TTW) or 3 or 4 leptons (TTZ)

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

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

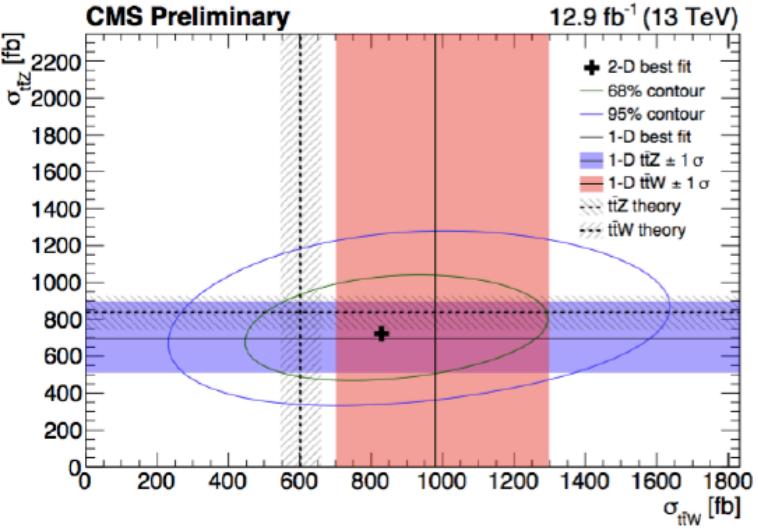
2 leptons

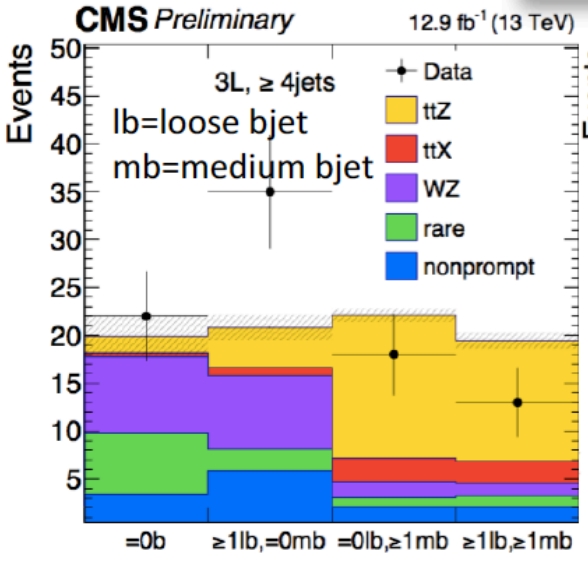
ttW



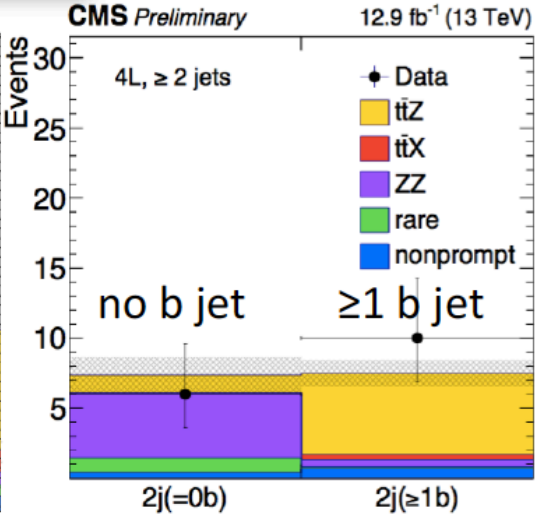
ttZ

3 leptons

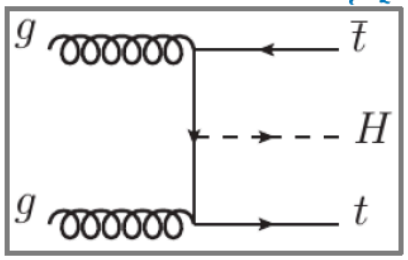




4 leptons



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

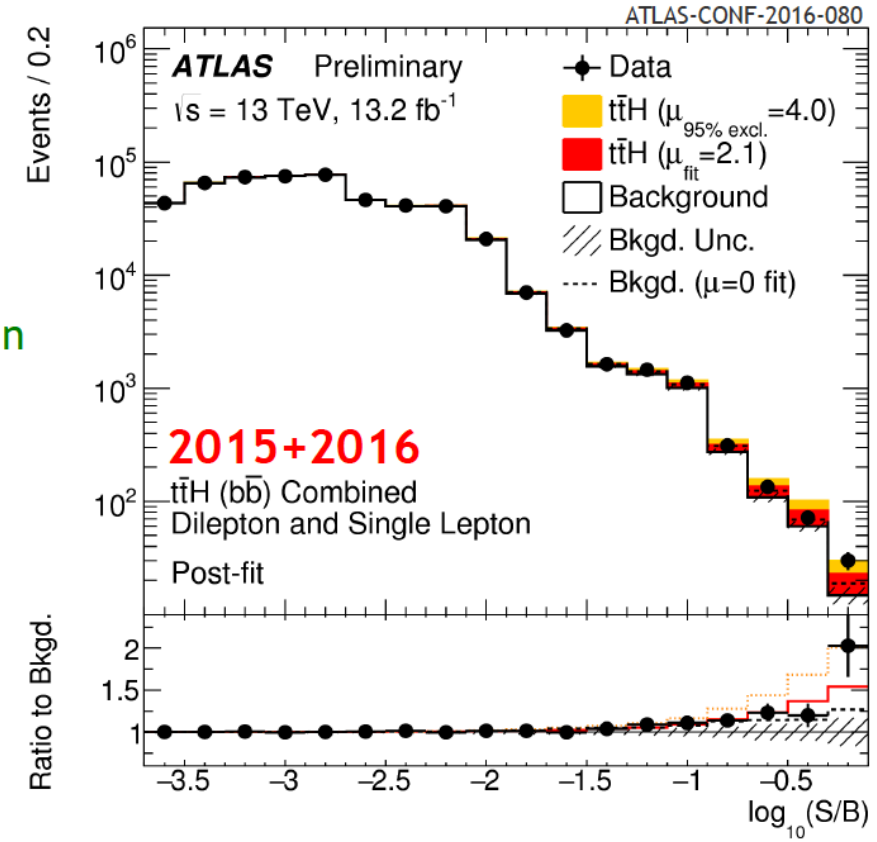
ttH, H→bb analysis

Complex final states

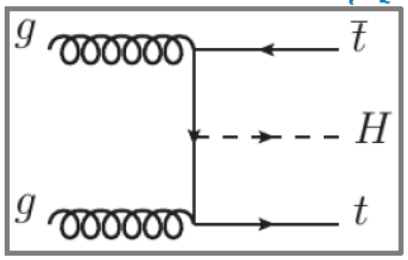
- 1ℓ + 6jets (4 b-jets)
- 2ℓ + 4jets (4 b-jets)

Multiple selection regions help to constrain $t\bar{t}$+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
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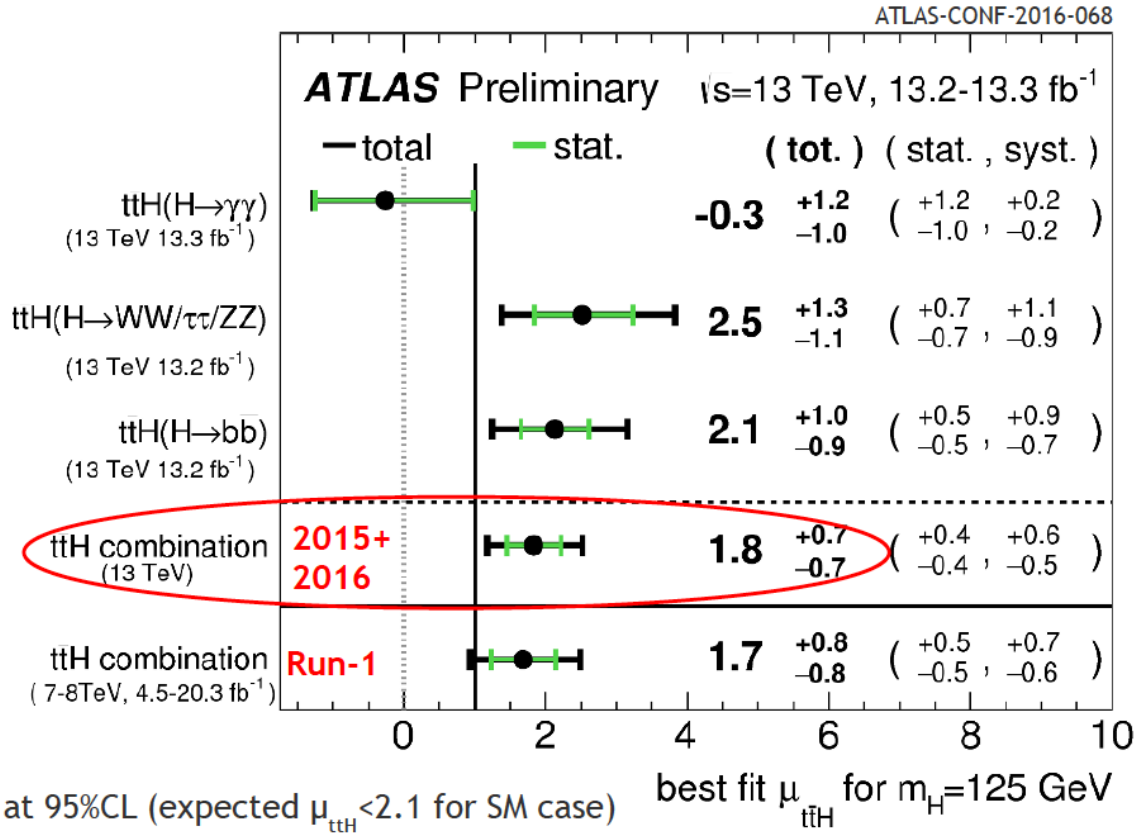
- ttH, H→γγ through H→γγ event categorisation

ttH combination

Combine all three 13 TeV analyses

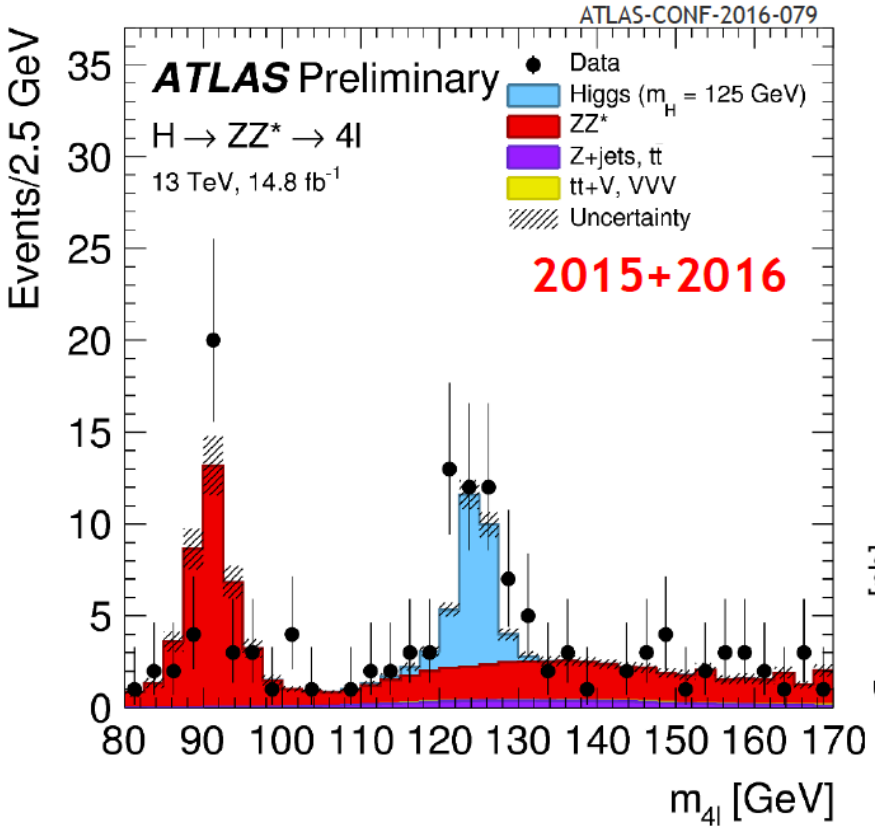
Signal strength μ expressed relative to SM expectation

Observed significance 2.8σ (expect 1.8σ)
Cf Run-1 expected 1.5σ



Upper limit on signal strength: μ_{ttH}<3.0 at 95%CL (expected μ_{ttH}<2.1 for SM case)

H→4ℓ & Cross-Section Combination



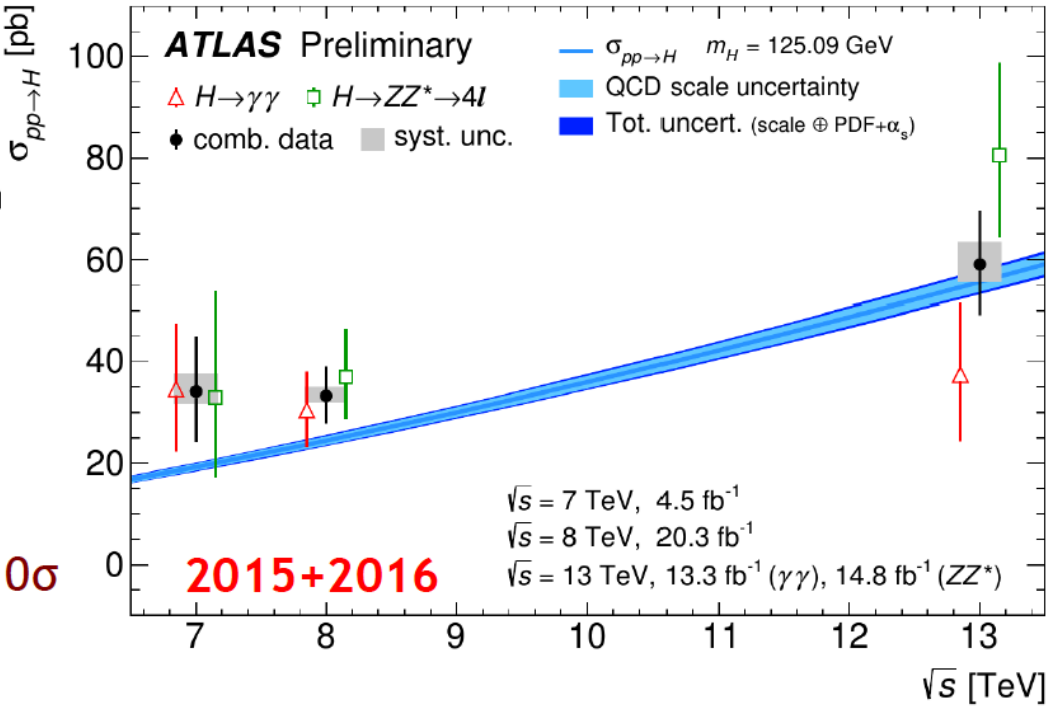
H→ZZ*→4ℓ: event categories again used

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

Combining γγ+4ℓ channels

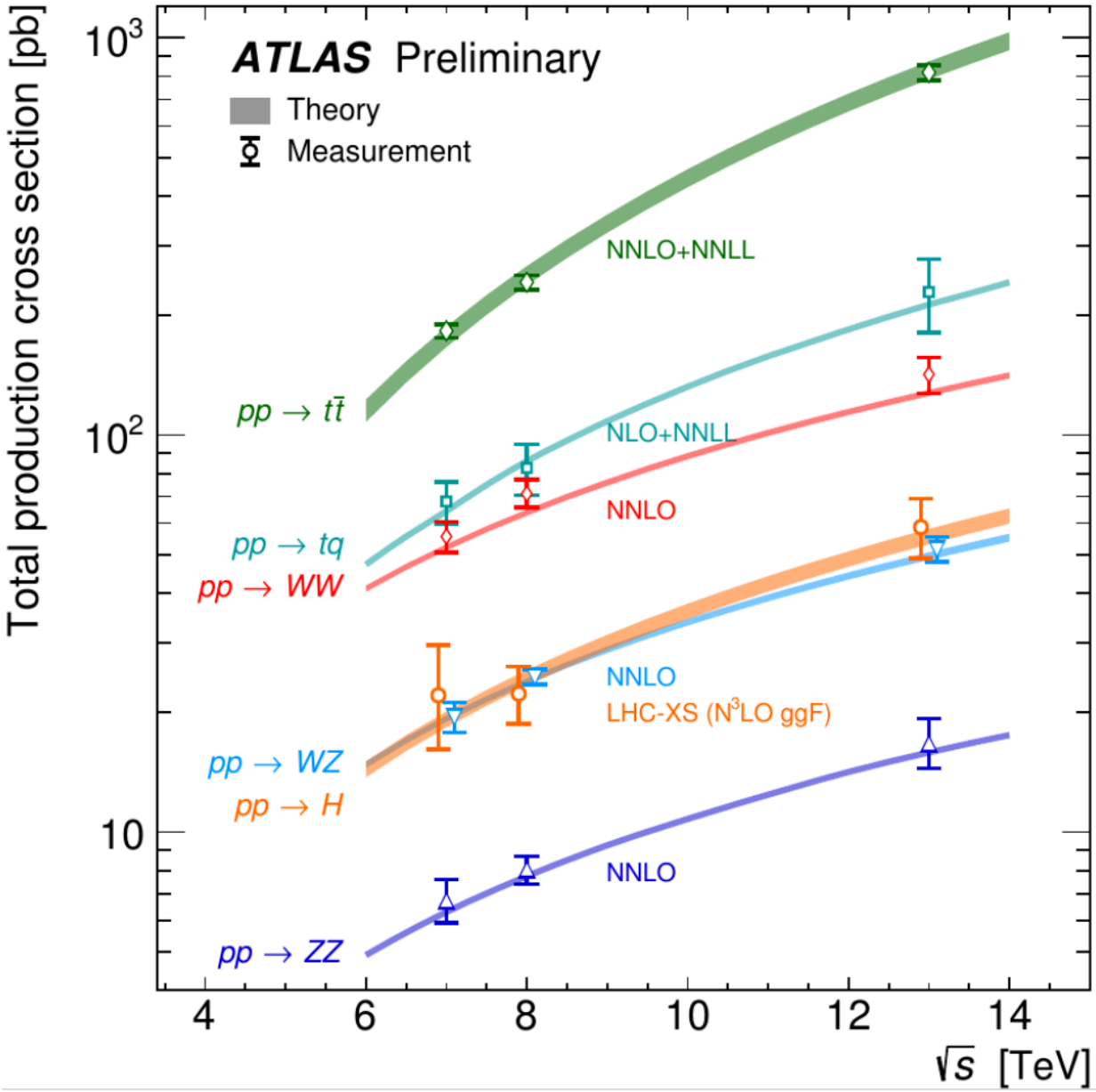
$\sigma(pp \to H+X, 13\ \text{TeV}) = 59.0^{+9.7}_{-9.2}\ (\text{stat.})\ ^{+4.4}_{-3.5}\ (\text{syst.})\ \text{pb}$

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



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

Overall significance at 13 TeV ~10σ



$pp \to t\bar{t}$
7 TeV, 4.6 fb^{-1}, Eur. Phys. J. C 74:3109 (2014)
8 TeV, 20.3 fb^{-1}, Eur. Phys. J. C 74:3109 (2014)
13 TeV, 3.2 fb^{-1}, arXiv:1606.02699

$pp \to tq$
7 TeV, 4.6 fb^{-1}, PRD 90, 112006 (2014)
8 TeV, 20.3 fb^{-1}, ATLAS-CONF-2014-007
13 TeV, 3.2 fb^{-1}, ATLAS-CONF-2015-079

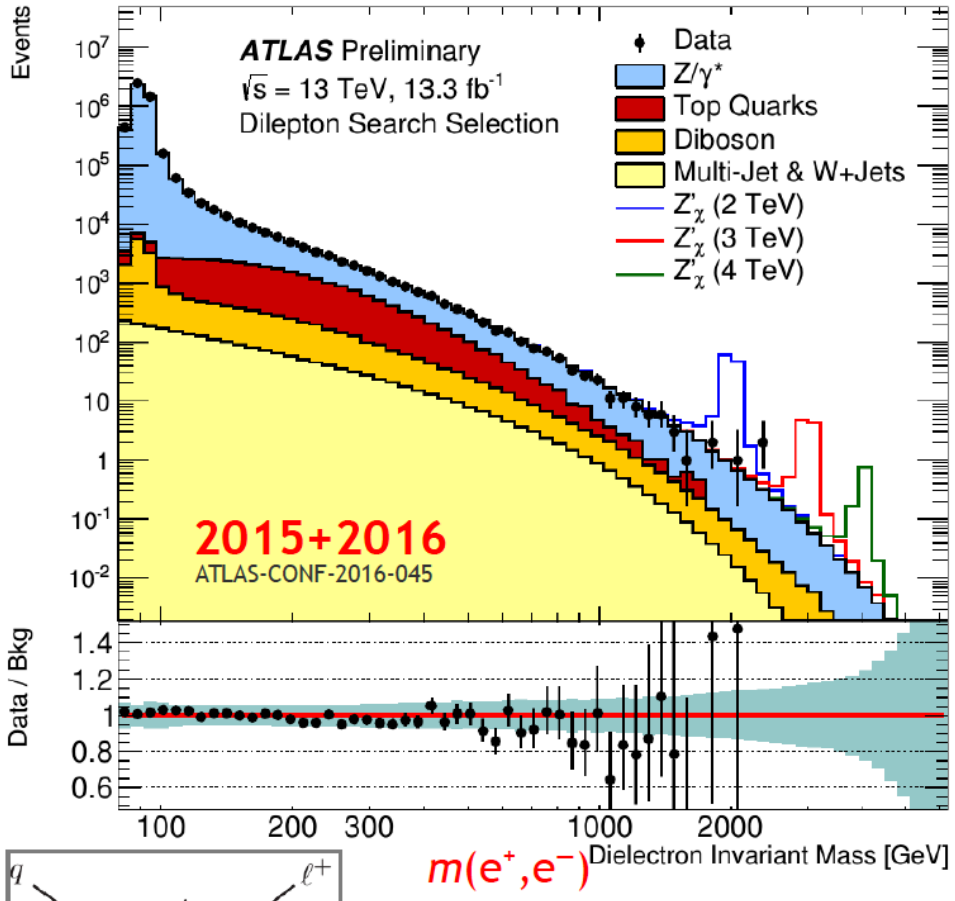
$pp \to WW$
7 TeV, 4.6 fb^{-1}, PRD 87, 112001 (2013)
8 TeV, 20.3 fb^{-1}, CERN-EP-2016-186
13 TeV, 3.2 fb^{-1}, ATLAS-CONF-2016-090

$pp \to WZ$
7 TeV, 4.6 fb^{-1}, Eur. Phys. J. C (2012) 72:2173
8 TeV, 20.3 fb^{-1}, PRD 93, 092004 (2016)
13 TeV, 3.2 fb^{-1}, arXiv:1606.04017

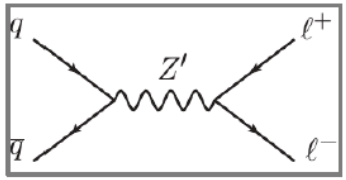
$pp \to H$
7 TeV, 4.5 fb^{-1}, Eur. Phys. J. C76 (2016) 6
8 TeV, 20.3 fb^{-1}, Eur. Phys. J. C76 (2016) 6
13 TeV, 13.3 fb^{-1}, CONF-HIGG-2016-28

$pp \to ZZ$
7 TeV, 4.6 fb^{-1}, JHEP 03, 128 (2013)
8 TeV, 20.3 fb^{-1}, ATLAS-CONF-2013-020
13 TeV, 3.2 fb^{-1}, PRL 116, 101801 (2016)

Dilepton Resonance Searches

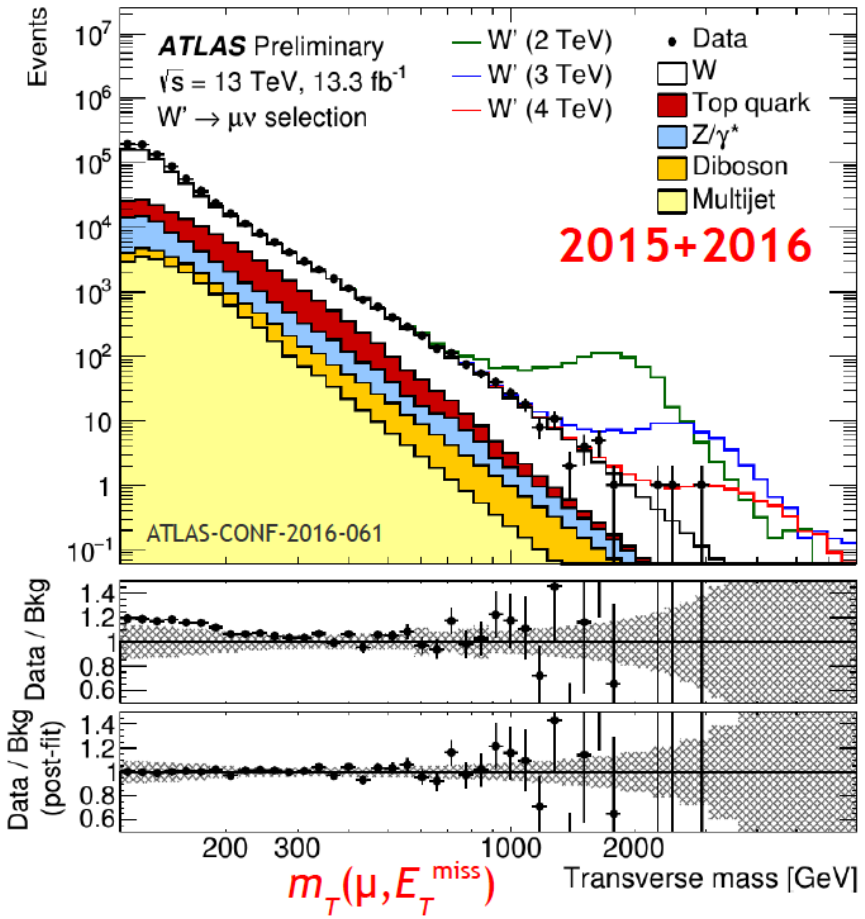


$m(e^+,e^-)$



Z'_{SSM} (@95%CL): m > 4.05 TeV

(Run-1 m>2.90 TeV)

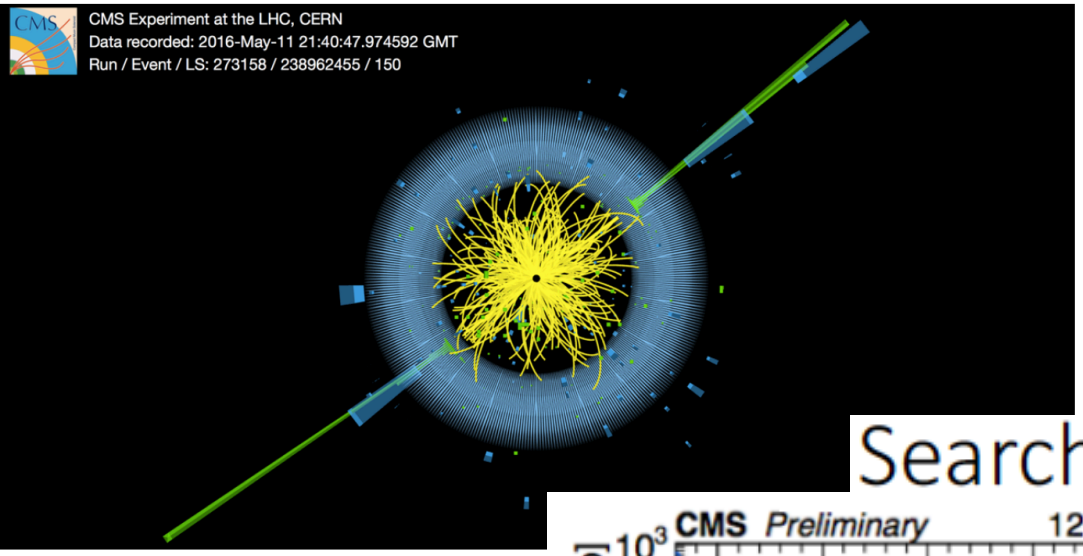


$m_T(\mu,E_T^{miss})$

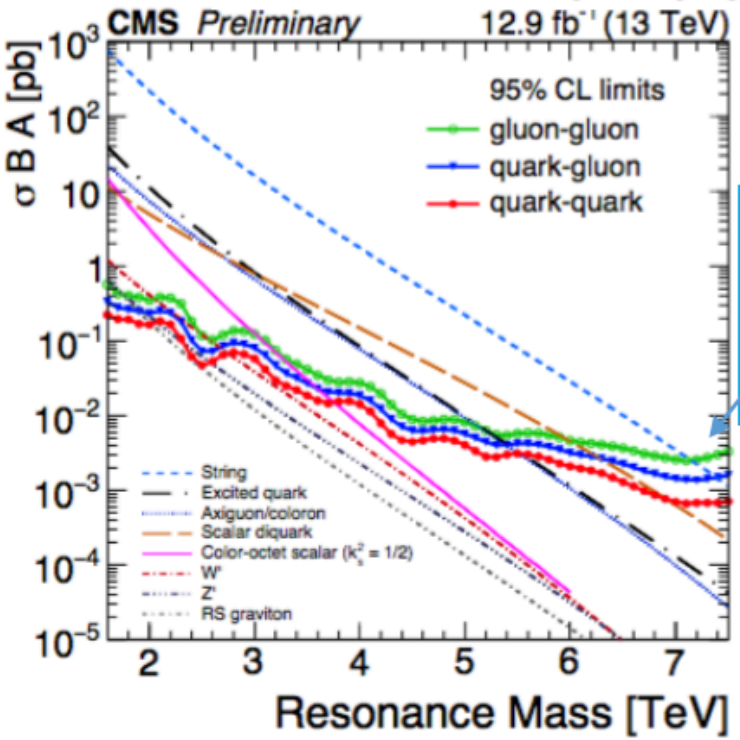
W' (@95%CL): m > 4.74 TeV

(Run-1 m>3.24 TeV)

Highest mass di-jet event: 7.7 TeV



Search for di-jets resonances

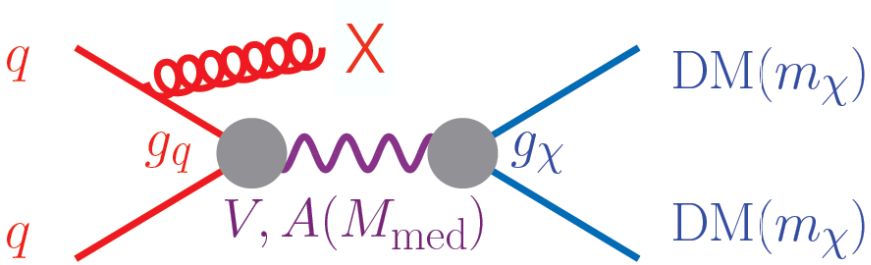


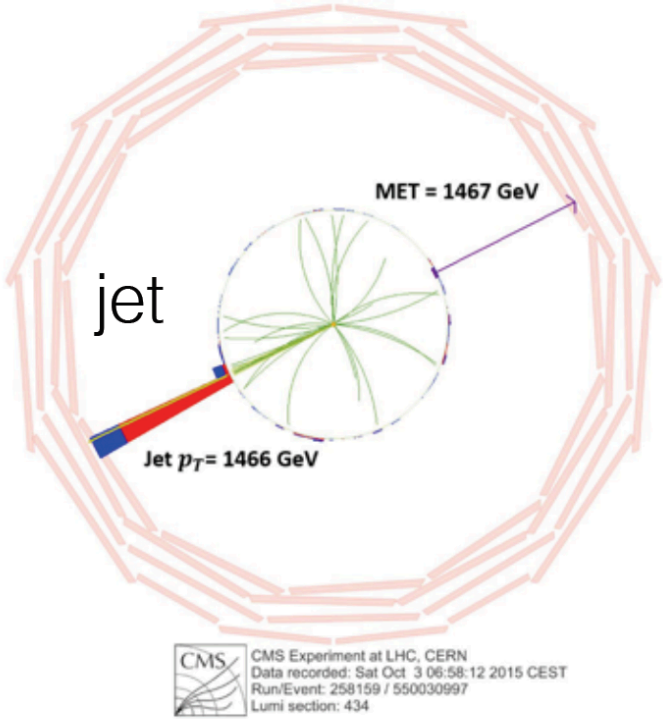
Strongest limit:
STRING resonances
excluded up to 7.4 TeV

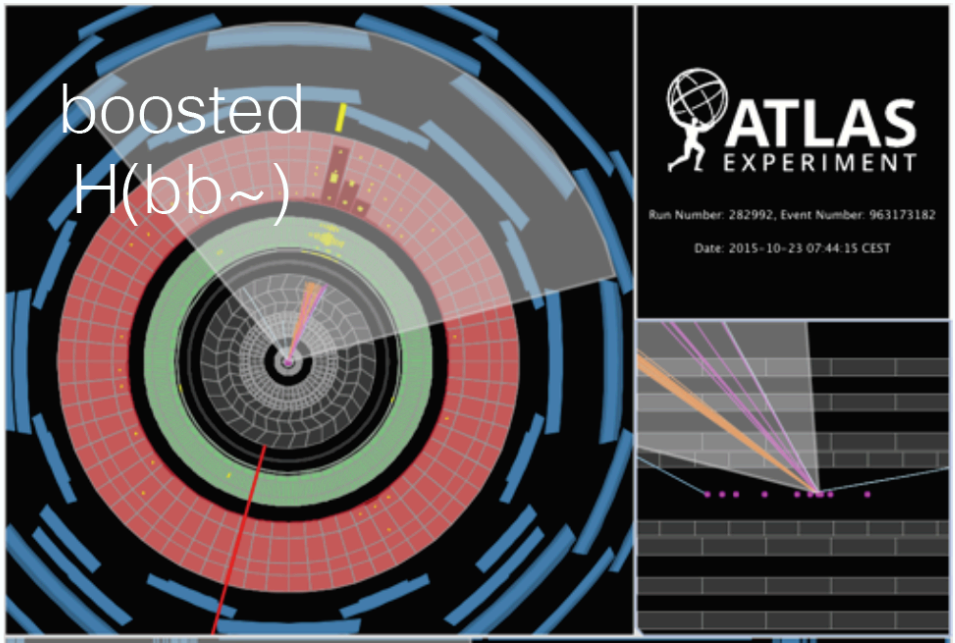
Collider Dark Matter Signature - Mono-X

ET^{miss}+X a.k.a. Mono-X

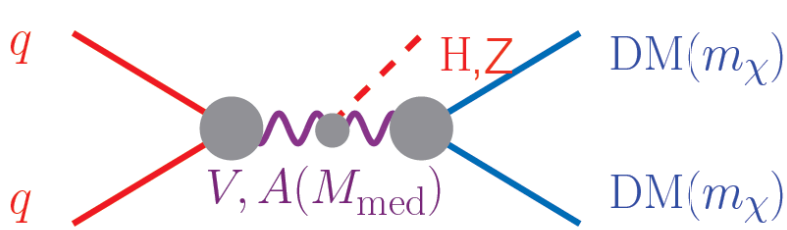
- X from ISR jet, b, t, γ, W, Z







- X from mixing with mediator

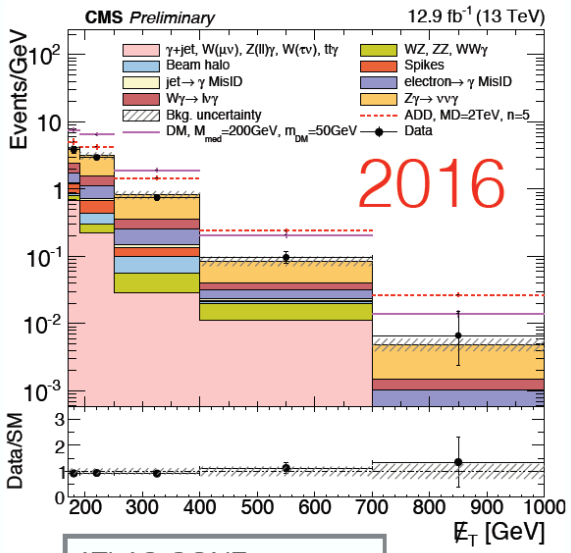


- X from paired $t\bar{t}$, $b\bar{b}$

Shih-Chieh Hsu

Mono-γ/W/Z/H

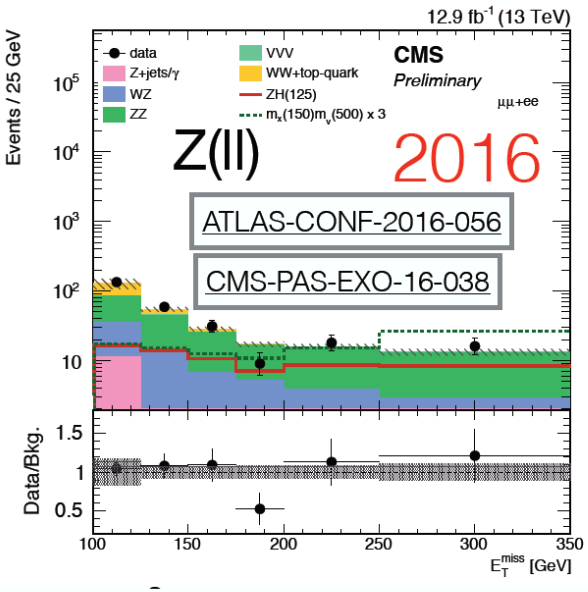
ET^{miss}+γ



ATLAS-CONF-2015-080

CMS-PAS-EXO-16-039

ET^{miss} + W/Z



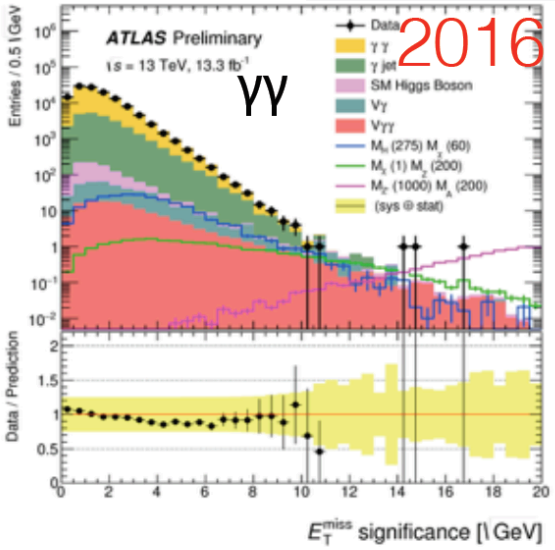
ATLAS-CONF-2016-056

CMS-PAS-EXO-16-038

ET^{miss}+H

CMS-PAS-EXO-16-011

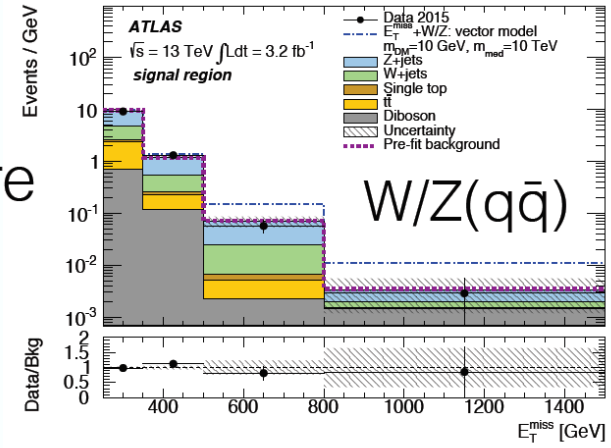
ATLAS-CONF-2016-087



EXOT-2015-08

CMS-PAS-EXO-16-037

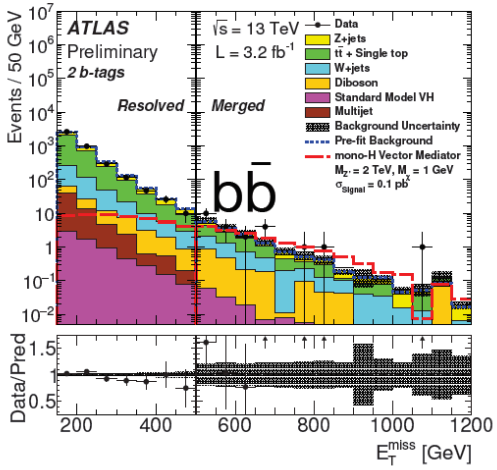
2015



ATLAS-CONF-2016-019

CMS-PAS-EXO-16-012

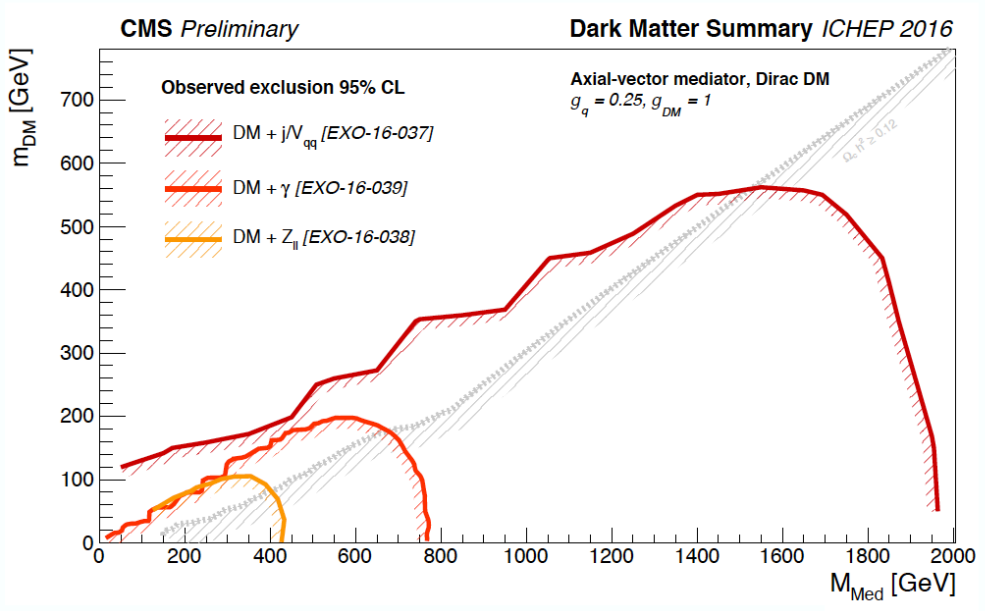
2015

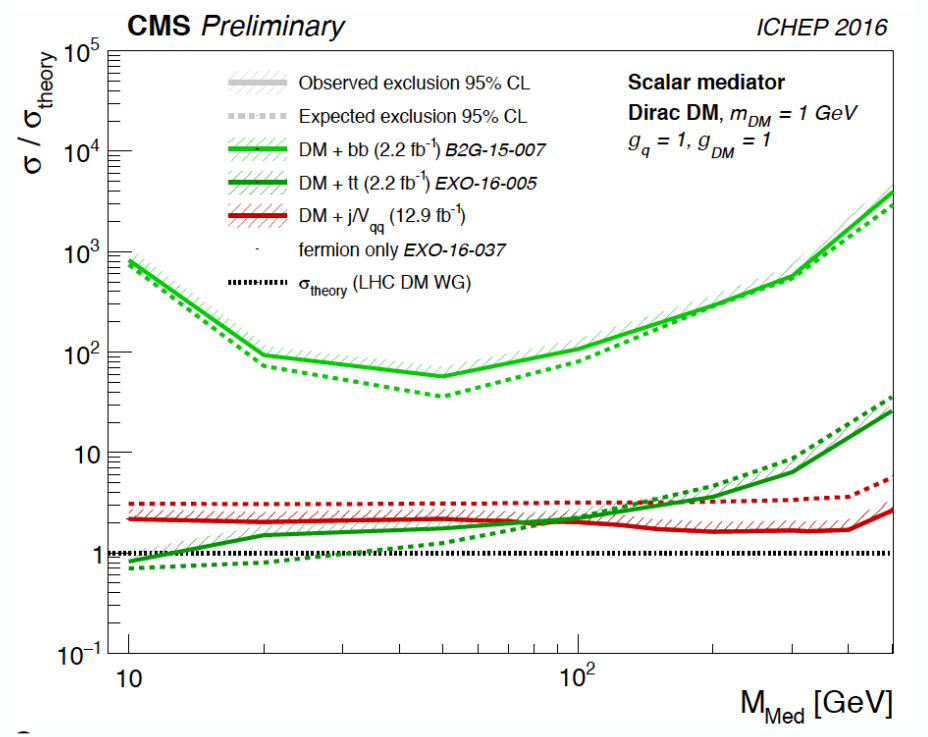


Boosted jet substructure technique is used in hadronic W/Z/H

Dark Matter exclusion limit

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

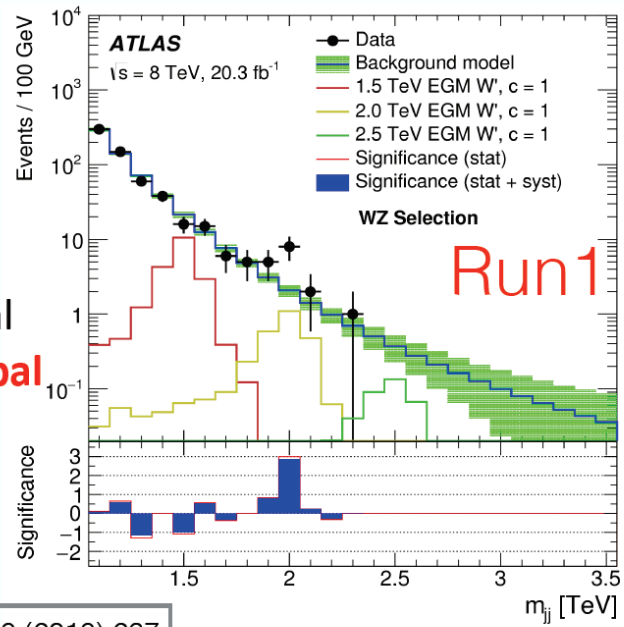




Shih-Chieh Hsu

Revisit diboson excesses in Run1

JHEP12(2015)055



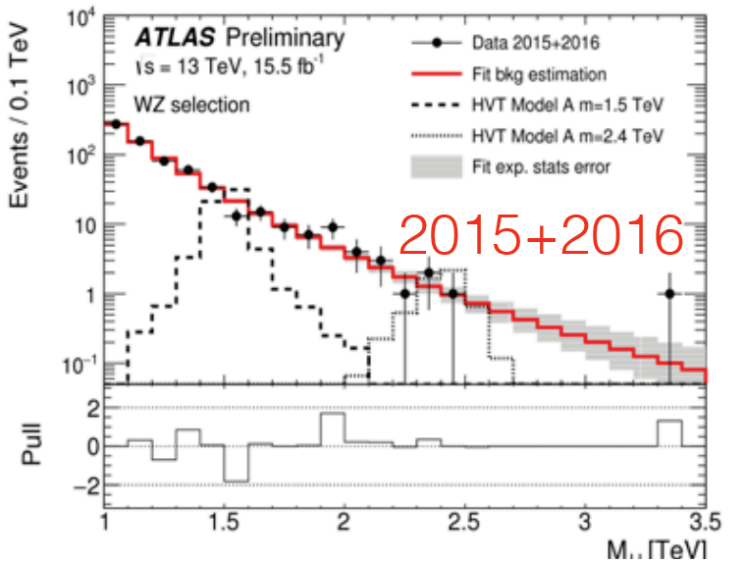
m= 2TeV

3.4σ local

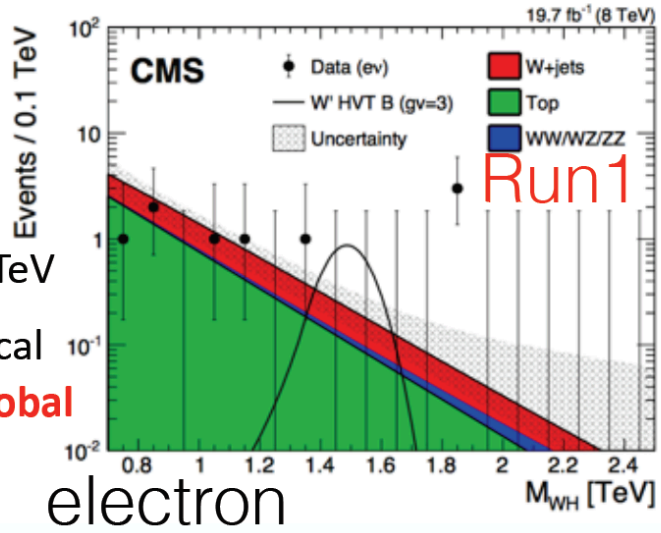
2.5σ global

Excesses not confirmed in Run2

ATL-CONF-2016-055



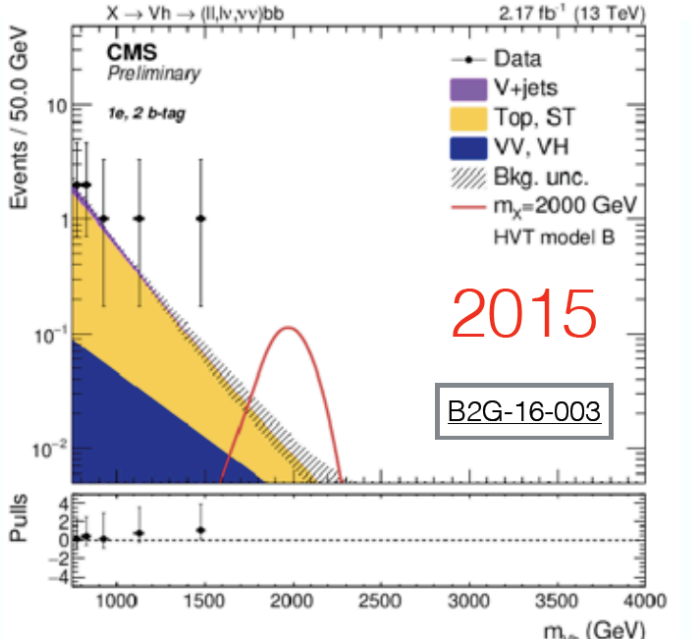
EPJC 76 (2016) 237



m=1.8 TeV

2.9σ local

1.9σ global

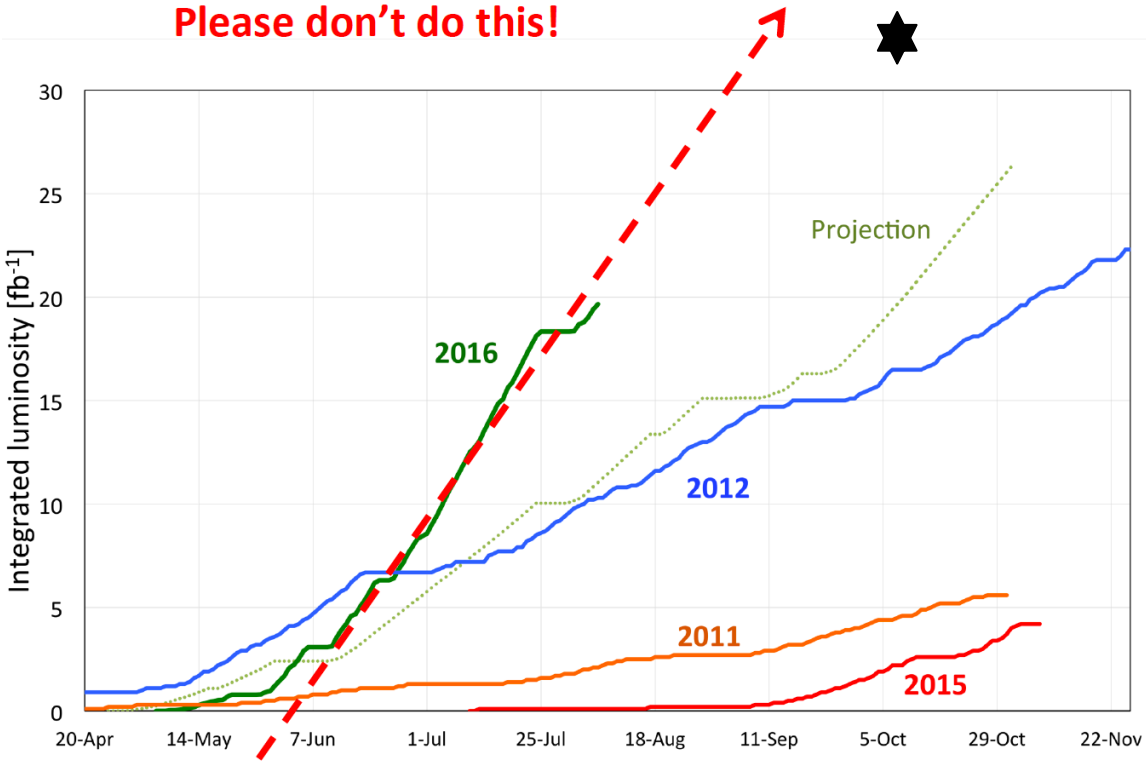


LHC prospects

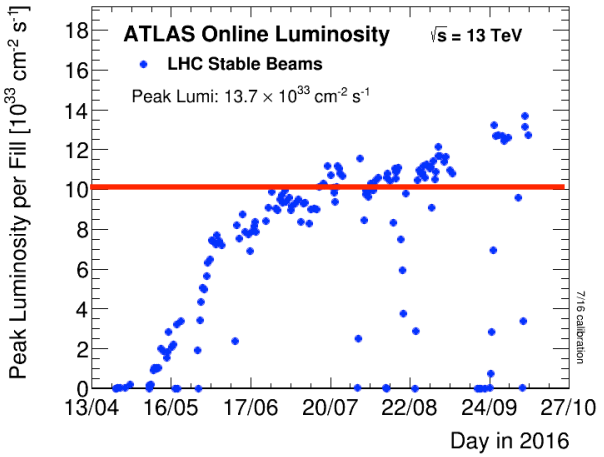
LHC Accelerator Performance

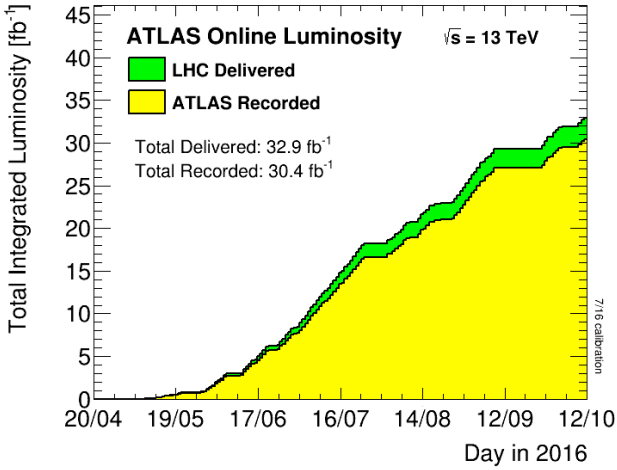
Mike Lamont

Please don't do this!



Current plots (11/10/16)





- Peak luminosity limited to ~1.7e34 by inner triplets
- ~40 fb^{-1}/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)]

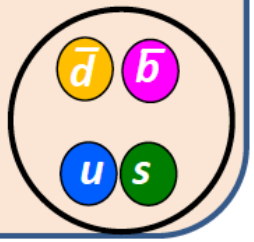
Claimed observation/evidence of an exotic state

- $X(5568)^\pm \to B_s^0\pi^\pm,\ B_s^0 \to J/\psi\phi,\ J/\psi \to \mu^+\mu^-,\ \phi \to K^+K^-$

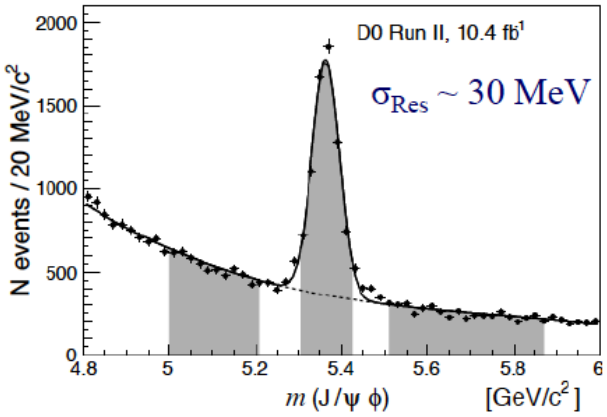
$$M = 5567.8 \pm 2.9^{+0.9}_{-1.9}\ \text{MeV}$$

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

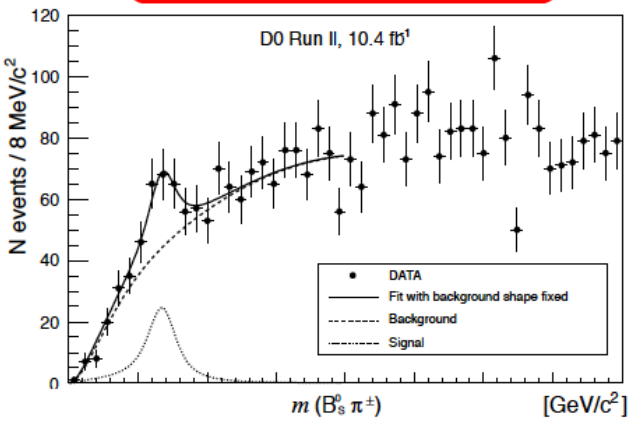
- Fraction of B_s^0 from $X^\pm$ decay: $\rho_X^{D\emptyset} = (8.6 \pm 1.9 \pm 1.4)\ \%$
- **If confirmed, would be unique with 4 different flavours**



N(Bs) ~ 5500

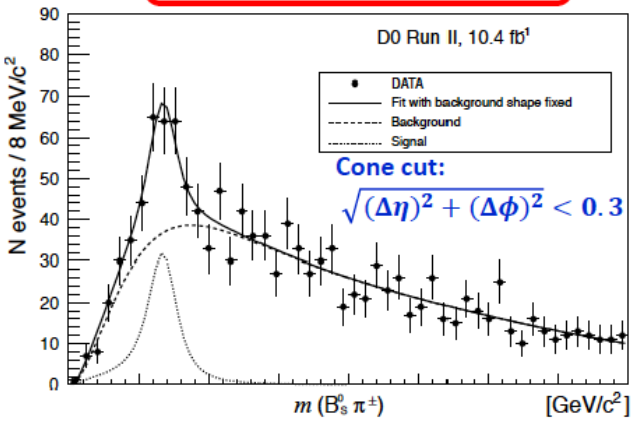


N(X) = 106 ± 23



3.9 σ

N(X) = 133 ± 31

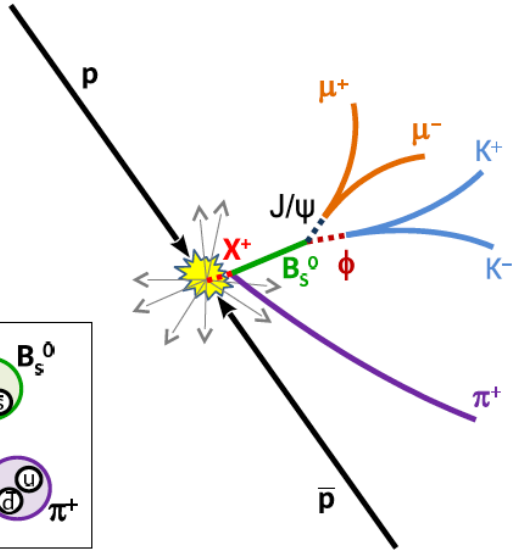


5.1 σ

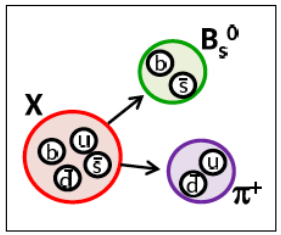
Signal significance

Exotic states at D0

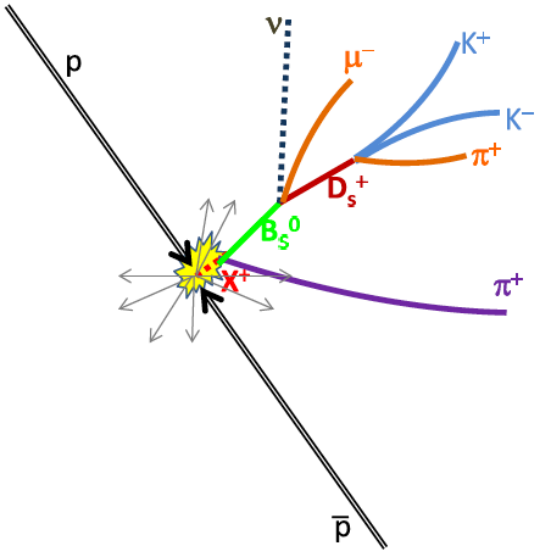
$X(5568) \to B_s\pi$



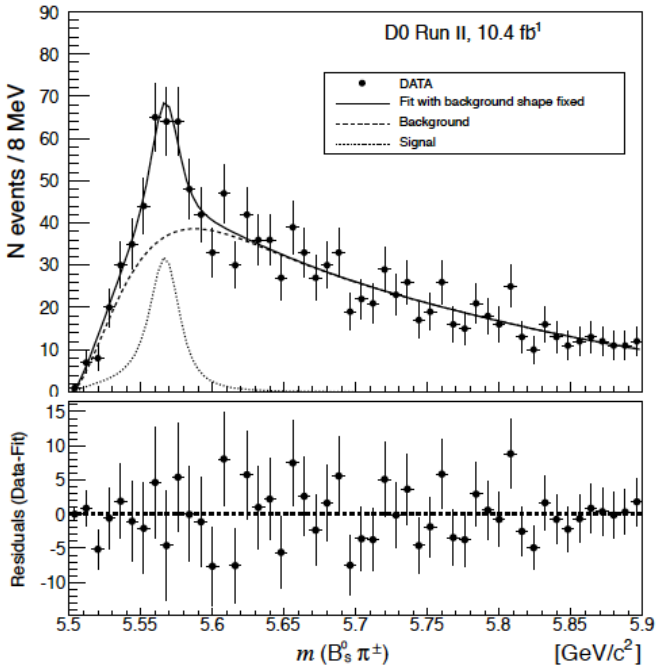
$B_s\pi^{\pm}$ state with $B_s^0 \to J/\psi\phi$
(PRL 117, 022003 (2016))



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



Results for the case with ΔR cut



$M_X = 5567.8 \pm 2.9$ MeV

$\Gamma_X = 21.9 \pm 6.4$ MeV

$N = 133 \pm 31$

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

("Local" $S = 6.6\sigma$).

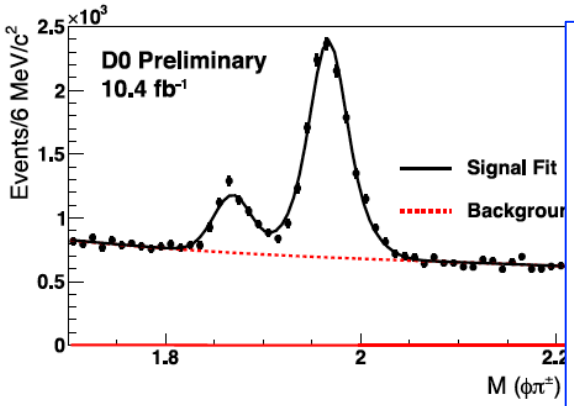
(PRL 117, 022003 (2016))

Signal is modeled by a relativistic Breit-Wigner function convolved with a Gaussian resolution of $\sigma = 3.8$ 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:
  $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.3$ (the "cone" cut)

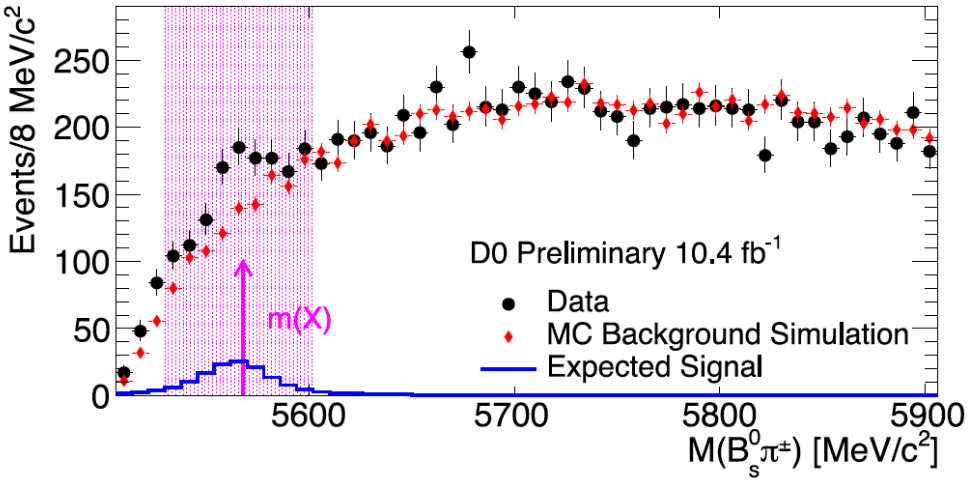
New channel: $B_s^0 \to D_s \mu\nu$ reconstruction

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



Comparison of data and simulated background

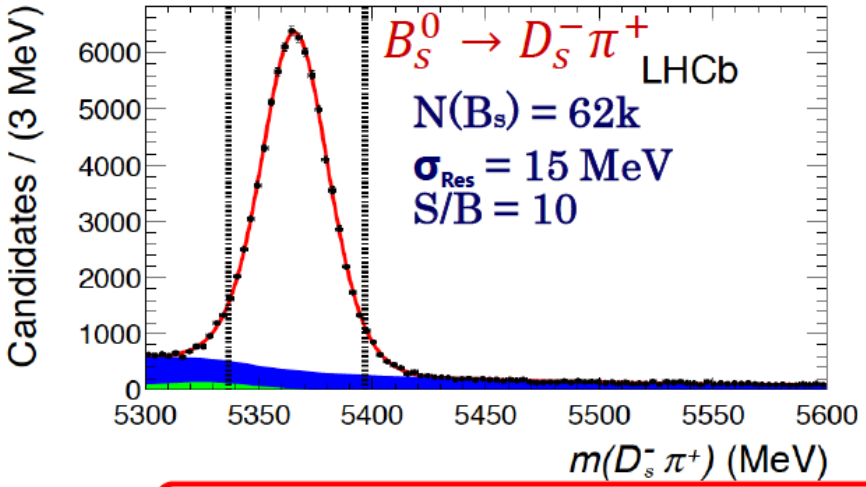
We simulate the component of the background due to random combinations of $B_s^0 \to D_s\mu\nu$ with a track assumed to be a pion and compare it to data.

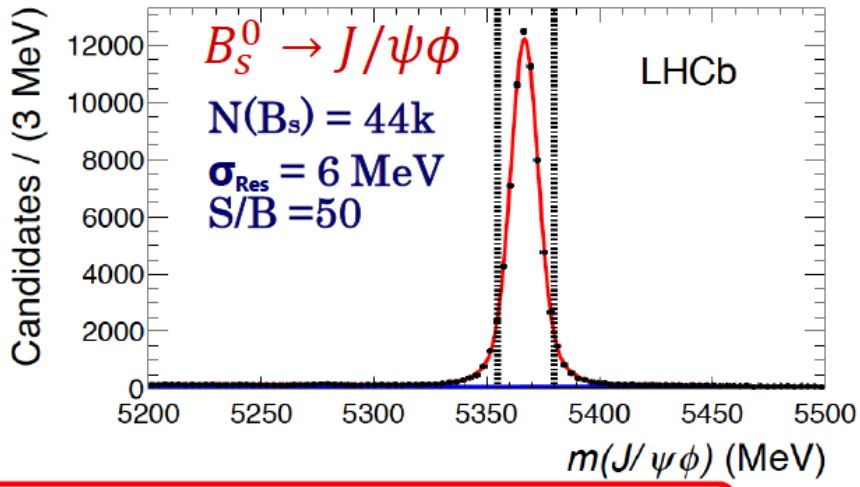


We see an enhancement whose mass, width and yield are consistent with those in the $X(5568) \to B_s^0\pi^\pm$, $B_s^0 \to J/\psi\phi$ publication.

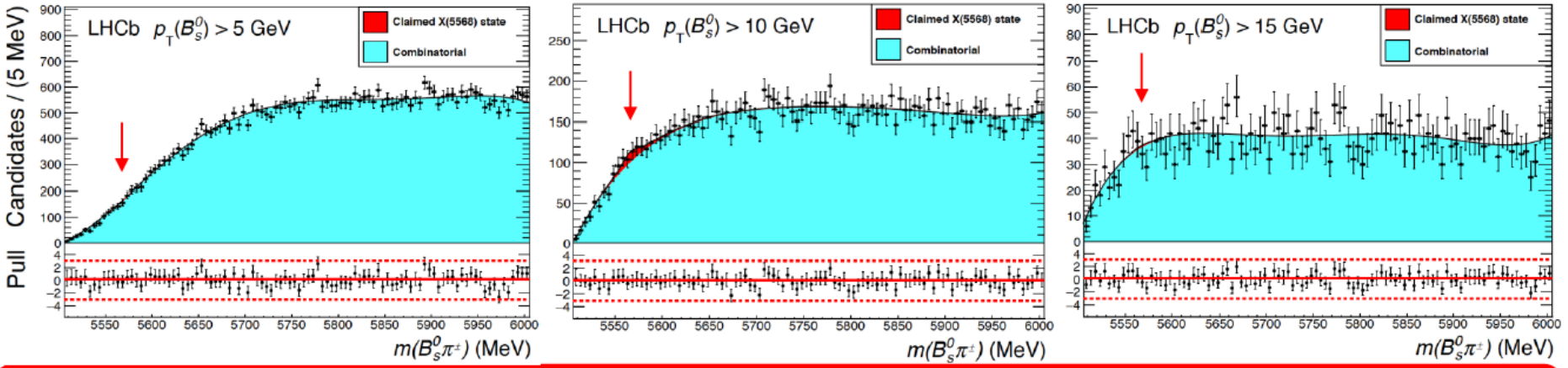
Samples from LHCb

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

LHCb-PAPER-2016-029
arXiv:1608.00435

- At 90% (95%) CL

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

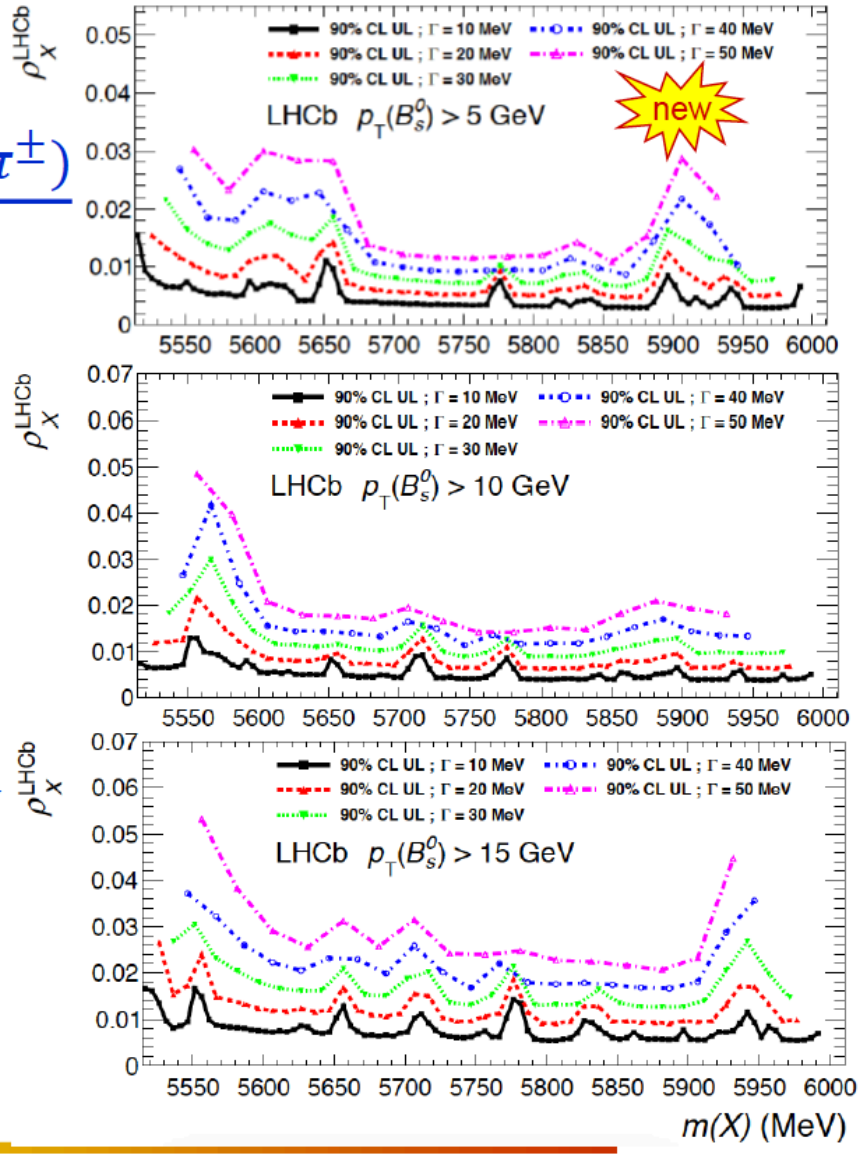
in LHCb acceptance

$$\rho_X^{\mathrm{LHCb}}(p_{\mathrm{T}}(B_s^0) > 5\,\mathrm{GeV}) < 0.011\ (0.012)$$
$$\rho_X^{\mathrm{LHCb}}(p_{\mathrm{T}}(B_s^0) > 10\,\mathrm{GeV}) < 0.021\ (0.024)$$
$$\rho_X^{\mathrm{LHCb}}(p_{\mathrm{T}}(B_s^0) > 15\,\mathrm{GeV}) < 0.018\ (0.020)$$

- No significant $B_s^0\pi^\pm$ states for any mass and width below 6 GeV

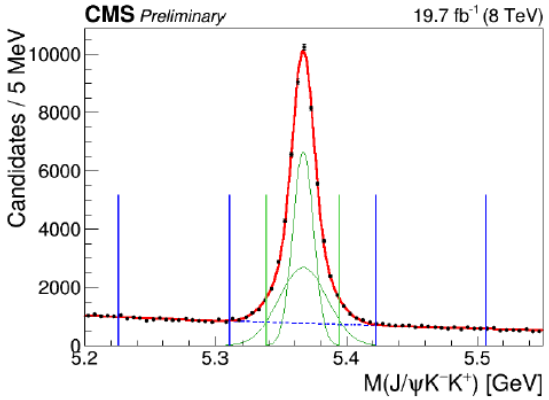
new

- Upper limit is set as a function of m(X) and Γ(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.

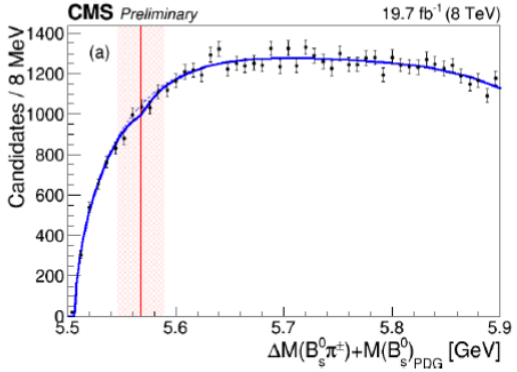


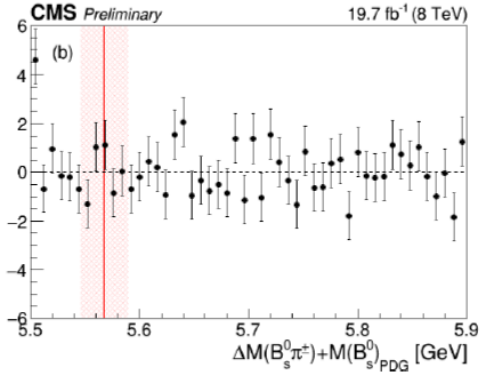
$$\rho_X \equiv \frac{\sigma(pp \rightarrow X(5558) + anything) \times B(X(5558) \rightarrow B_s\pi^\pm)}{\sigma(pp \rightarrow B_s + anything)} = \frac{N_X}{N_{B_s}} \frac{\varepsilon_{B_s}}{\varepsilon_X}$$

EDUARD DE LA CRUZ BURELO

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

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





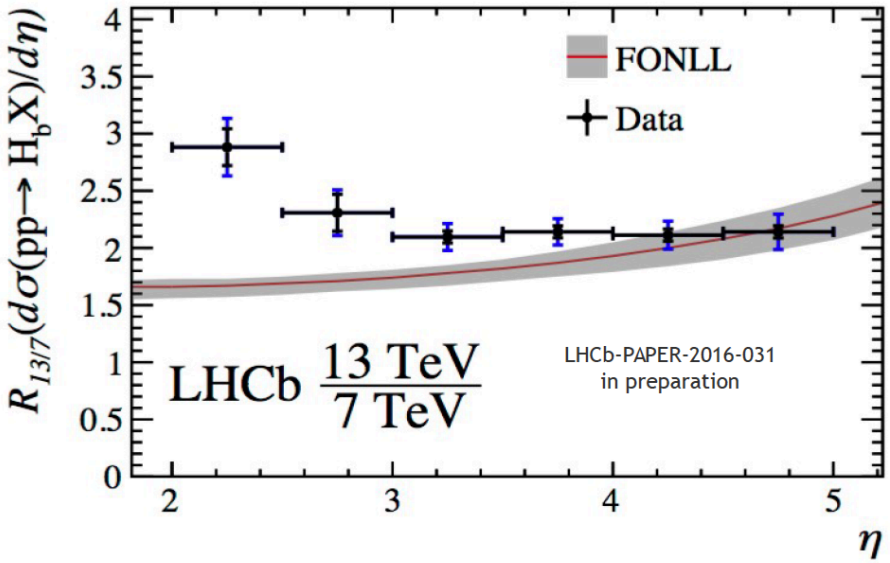
$\rho_X < 3.9\%$ @95% $C.L.$

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

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

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

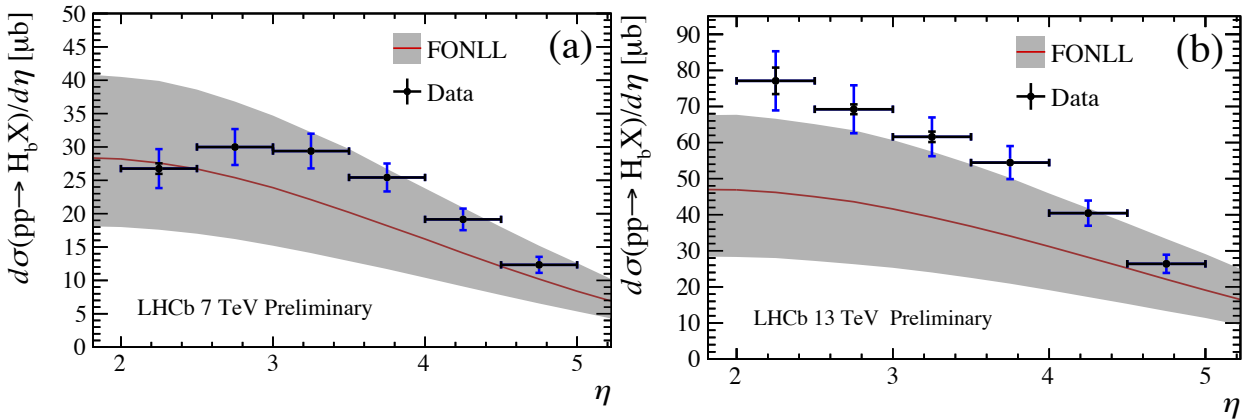
- The measurement is made using semileptonic decays of b-hadrons



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

- Calls for further theoretical progress

M. Artuso



Why study CPV ?

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

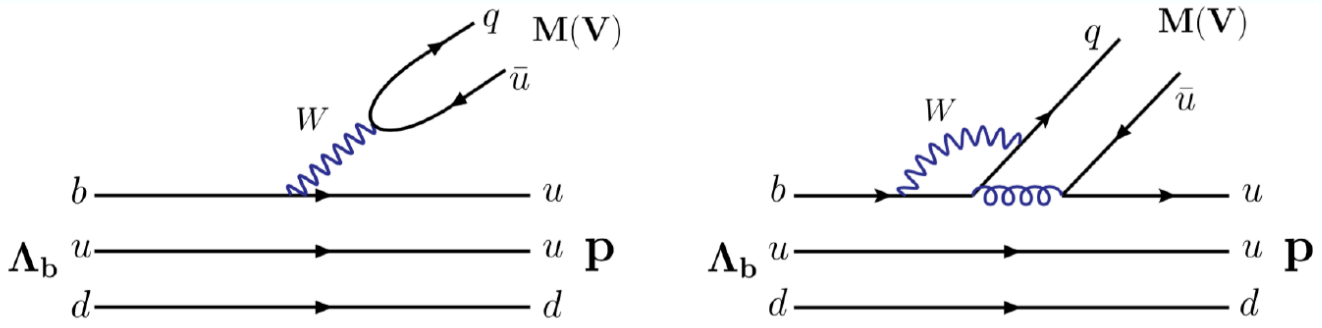
Possibly there are other sources of CPV beyond SM. Need to search for CPV effects extensively

[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)

Beauty baryons at LHCb

- b-baryon sector, relatively unexplored territory to search for CPV

possible large interference between tree and penguin diagrams



✓ Potentially large CPV effects in charmless Λ_b^0 decays, up to A_{CP}=20%

Phys. Rev. D 91, 116007 (2015)

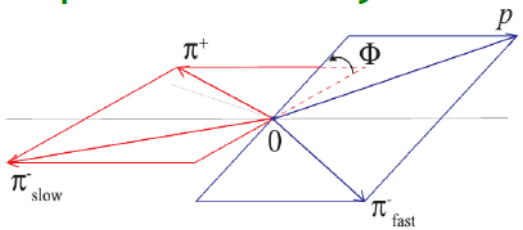
	Our result	pQCD [4]	Data
$10^2\mathcal{A}_{CP}(\Lambda_b \to pK^-)$	$5.8 \pm 0.2 \pm 0.1$	-5^{+26}_{-5}	$-10 \pm 8 \pm 4$ [7]
$10^2\mathcal{A}_{CP}(\Lambda_b \to p\pi^-)$	$-3.9 \pm 0.2 \pm 0.0$	-31^{+43}_{-1}	$6 \pm 7 \pm 3$ [7]
$10^2\mathcal{A}_{CP}(\Lambda_b \to pK^{*-})$	$19.6 \pm 1.3 \pm 1.0$	...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

CP Violation at LHCb - Λ_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 $\Lambda_b \to p\pi^-\pi^+\pi^-$

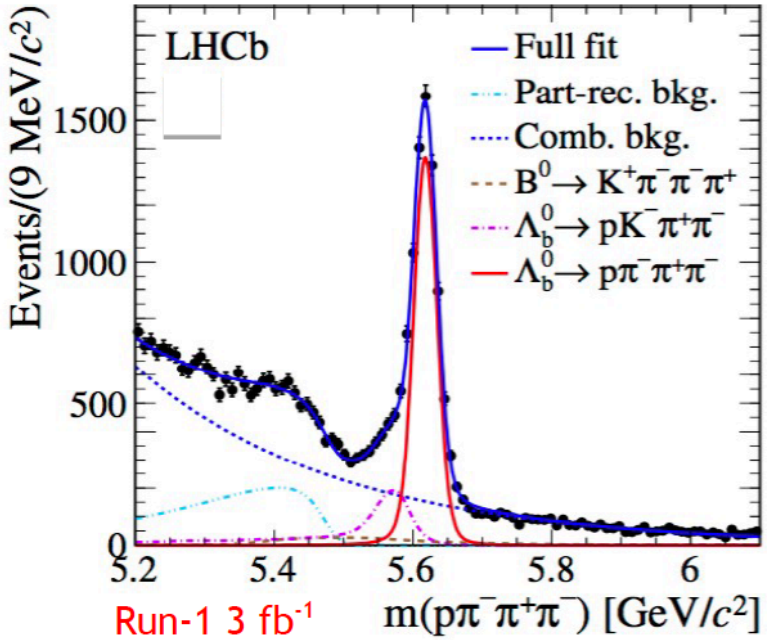
- Searching for local CP-violating effects in $\Lambda_b \to p\pi^-\pi^+\pi^-$ decays as a function of the relative orientation between the decay planes formed by the $p\pi^-$ and $\pi^+\pi^-$ systems (Φ)

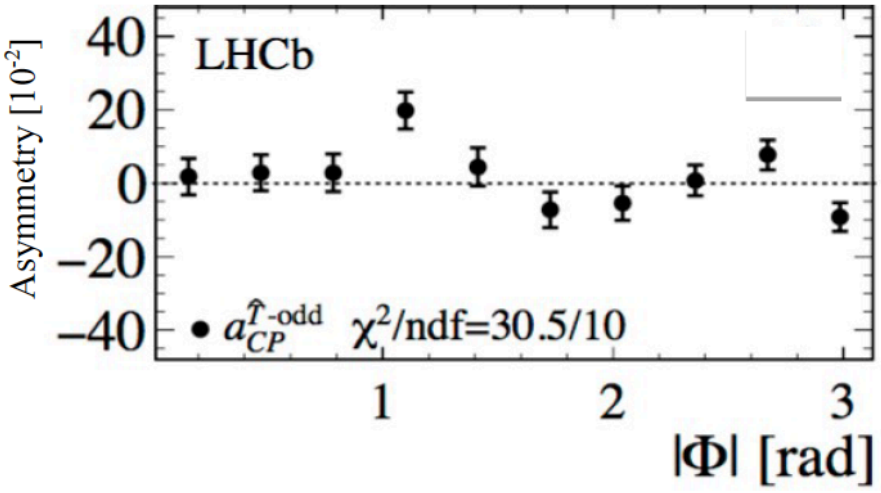


- Evidence is found for CP violation at the 3.3σ level

First evidence of CP violation in the baryon sector

LHCb-PAPER-2016-030 in preparation

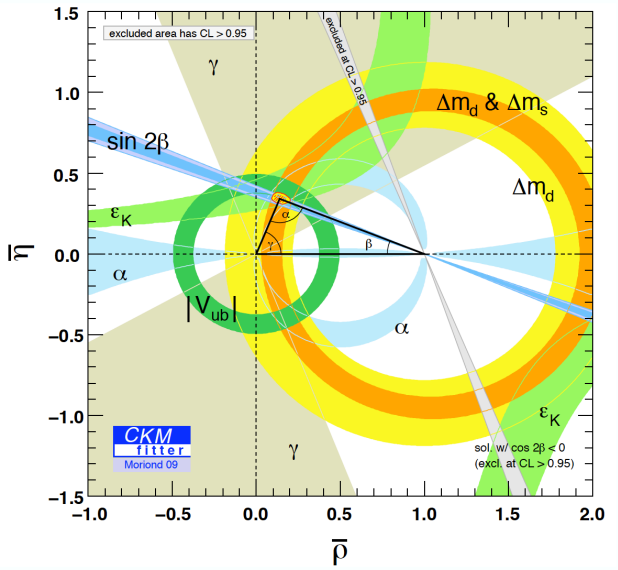




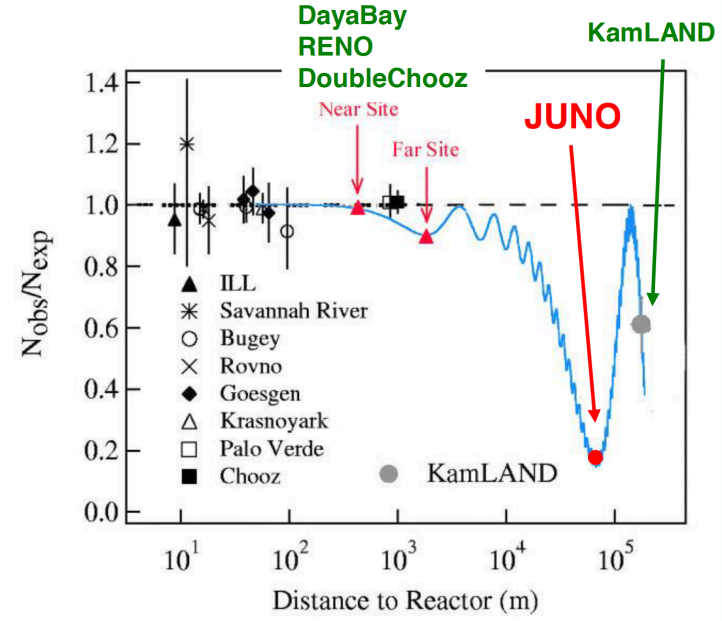
Charged lepton: results and future prospects

Now we know that

Quarks mix



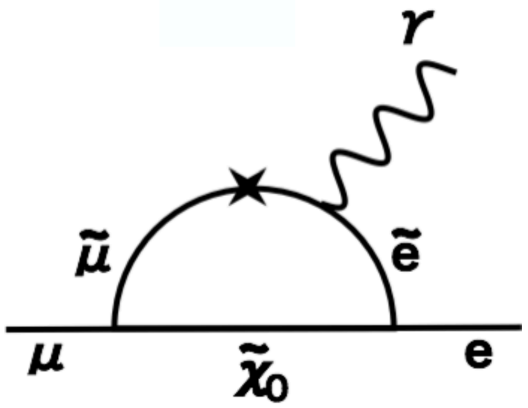
Neutrinos oscillate



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 ν-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



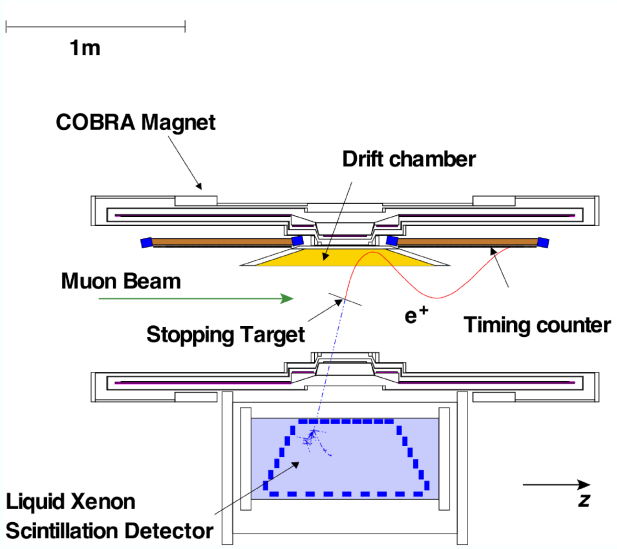
Hints of new physics in charged lepton sector

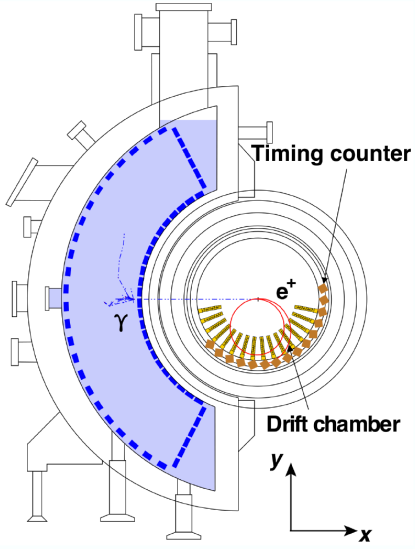
- **Muon g-2 : 3.6 σ difference from the SM value (BNL E821)**
  - Next generation experiments at Fermilab (first result in FY2017—2018) and J-PARC
- **Proton radius puzzle : 7 σ difference between ep and μp (CREMA@PSI)**
  - e-μ universality violation ?
  - New results expected from CREMA, MUSE, PRad,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

$\mu \rightarrow e\gamma$: MEG

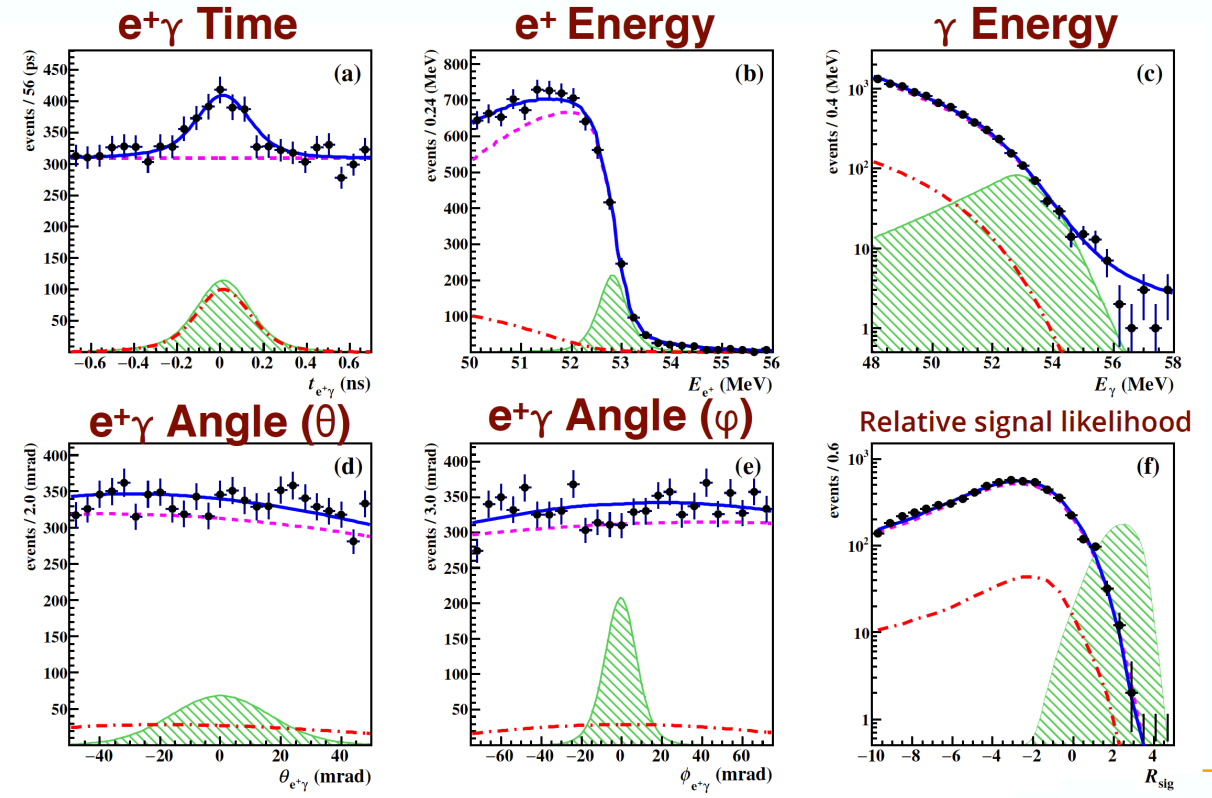
- Searching for cLFV decay $\mu^+ \rightarrow e^+\gamma$
- Most intense DC μ^+ beam, 3×10^7 μ/sec @ PSI, Switzerland
- Detector
  - Photon : Largest LXe photon detector
  - Positron : gradient B-field, Ultra light drift chamber, high resolution e^+ timing counter
- Data taking in 2008-2013
- Previous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

    PRL, 110 201801 (2013)
- Analysis of full data completed





MEG : Fit on the full data



Data consistent with BG PDF

Final result of MEG

No excess was found and the new UL was set

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

arXiv:1605.05081
ready for publication from EPJC

×30 more stringent than the previous experiment

(×10^{-13})	2009-2011 data	2012-2013 data	All combined
Best Fit	-1.3	-5.5	-2.2
90% CL Upper limit	6.1	7.9	**4.2**
Sensitivity	8.0	8.2	**5.3**

Previous limit with 2009-2011 dataset : 5.7×10^{-13}

UL : Feldman-cousins with profile-likelihood ratio ordering

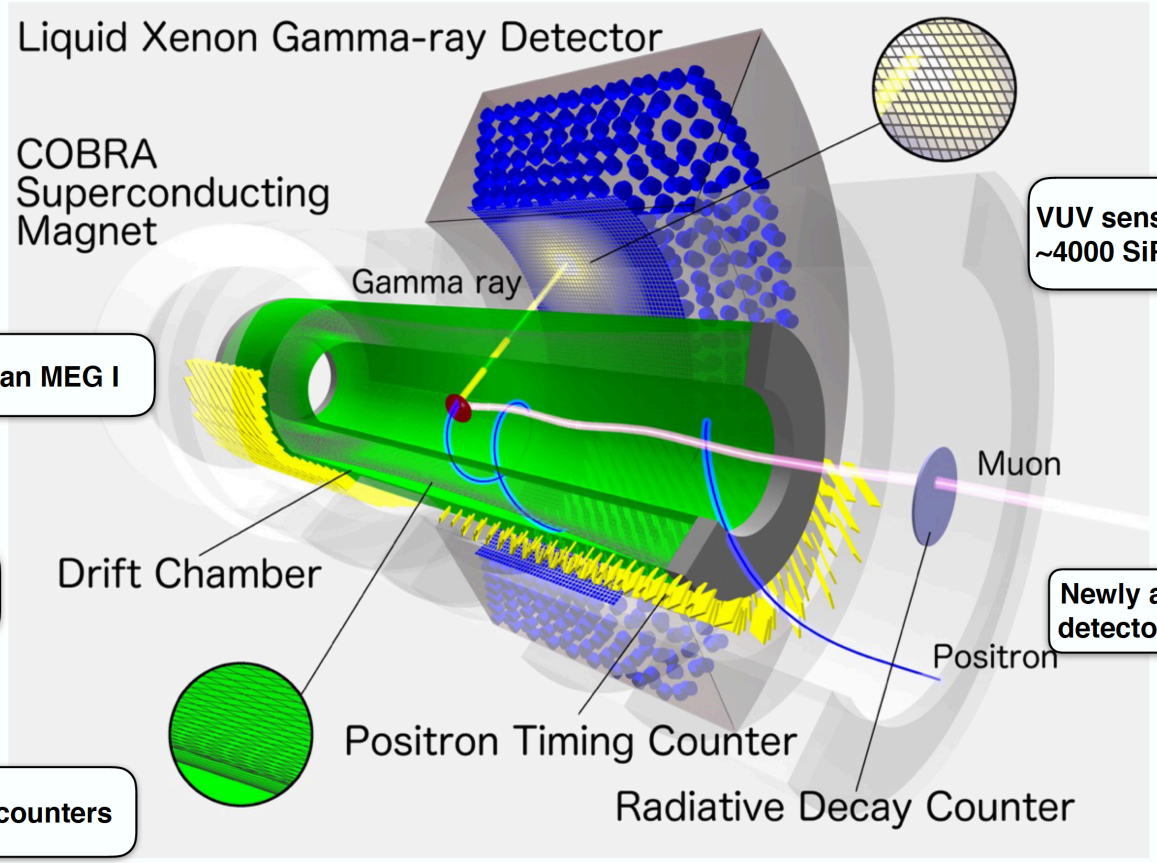
Systematic uncertainties

UL increase by

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

Future : MEG II

Upgrades for 10 times higher sensitivity



Beam intensity >2 higher than MEG I

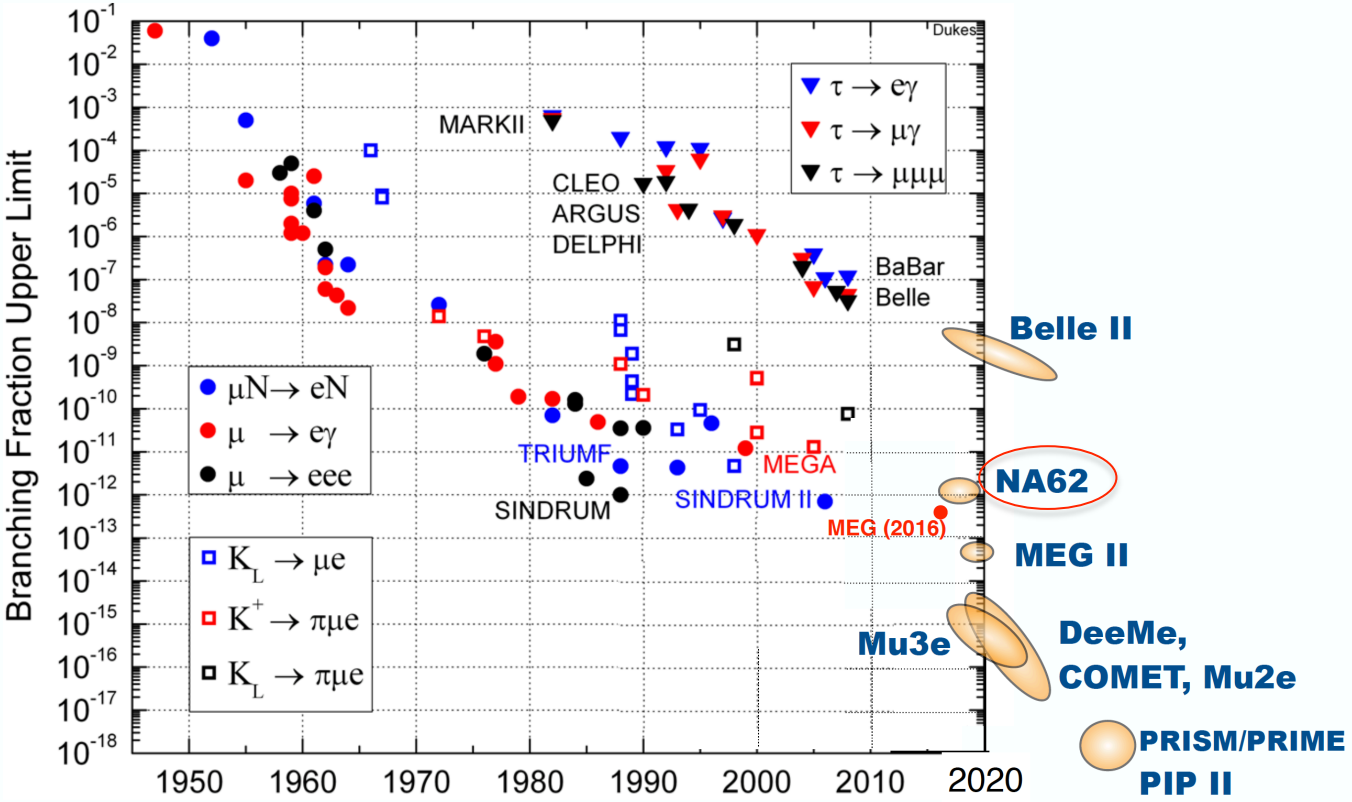
VUV sensitive SiPMs ~4000 SiPM in the detector

Single volume, stereo wire chamber

Newly added e^+ detector for BG veto

highly segmented plastic counters

Prospects

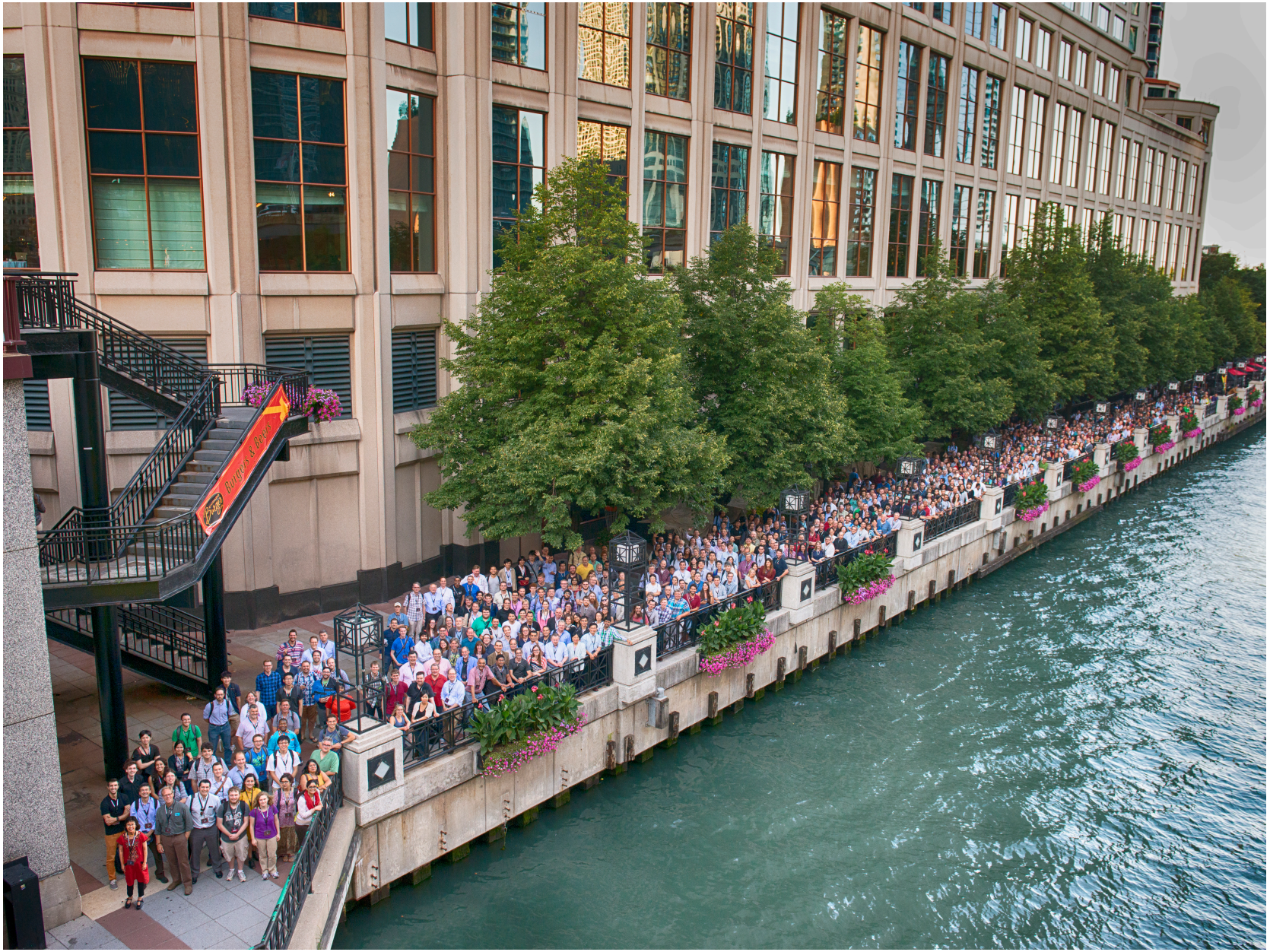

Branching Fraction Upper Limit
Dukes
MARKII
CLEO
ARGUS
DELPHI
BaBar
Belle
TRIUMF
MEGA
SINDRUM
SINDRUM II
MEG (2016)
τ → eγ
τ → μγ
τ → μμμ
μN→ eN
μ → eγ
μ → eee
K_L → μe
K+ → πμe
K_L → πμe
Belle II
NA62
MEG II
Mu3e
DeeMe,
COMET, Mu2e
PRISM/PRIME
PIP II

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)

- 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)

2018: ICHEP in Seoul (Korea)

Future ICHEP and Lepton conferences

- Lepton Photon 2019:
  - ✓ Toronto (Canada)

- ICHEP 2020:
  - ✓ Prague (Czech Republic)