



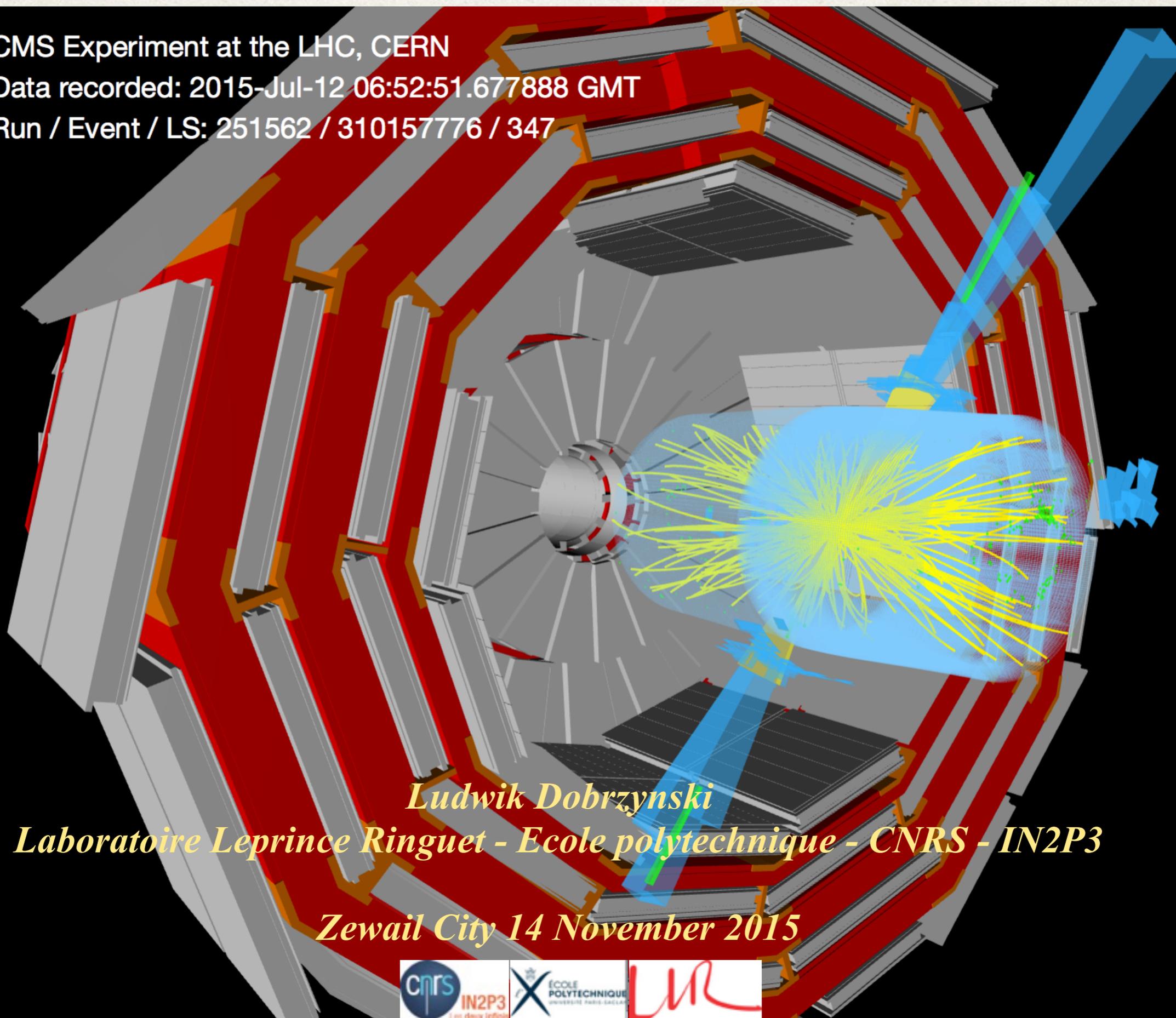
# First look at 13TeV data



CMS Experiment at the LHC, CERN

Data recorded: 2015-Jul-12 06:52:51.677888 GMT

Run / Event / LS: 251562 / 310157776 / 347



*Ludwik Dobrzynski*

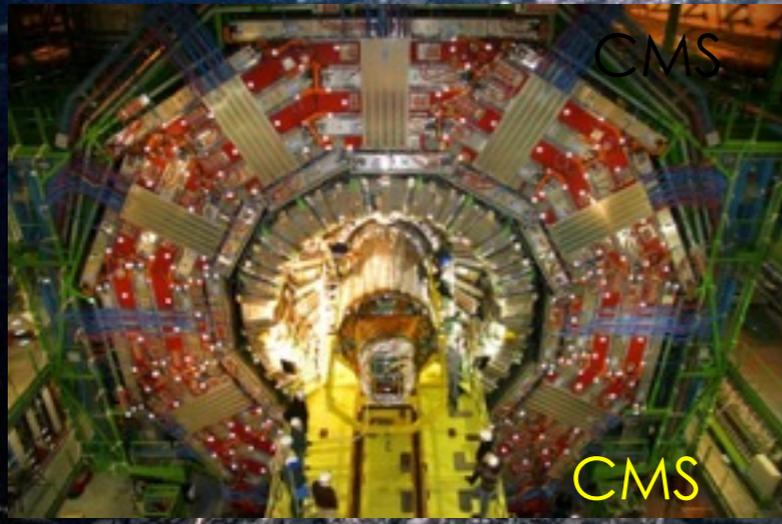
*Laboratoire Leprince Ringuet - Ecole polytechnique - CNRS - IN2P3*

*Zewail City 14 November 2015*

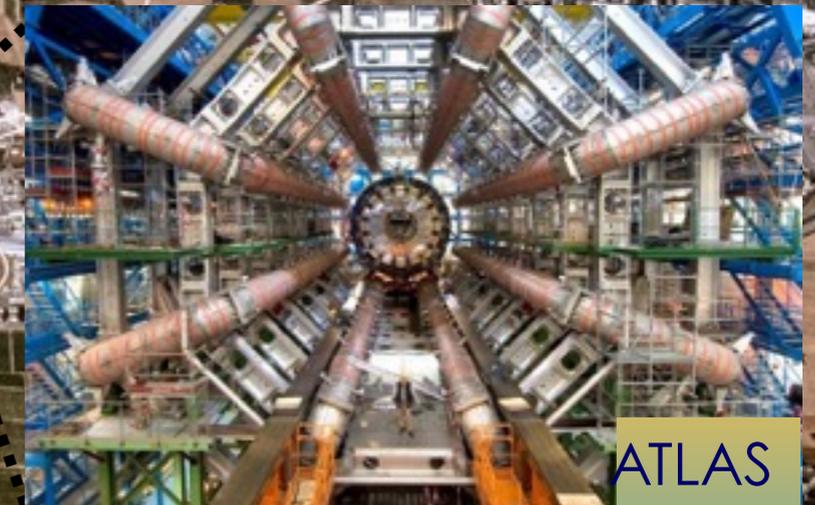
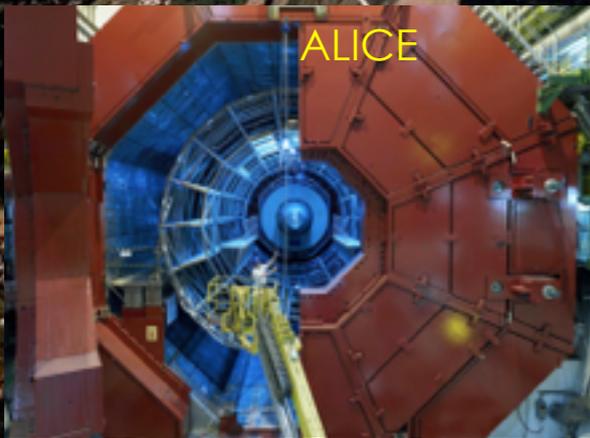


# Enter a New Era in Fundamental Science

Start-up of the Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is the most exciting turning point in particle physics.



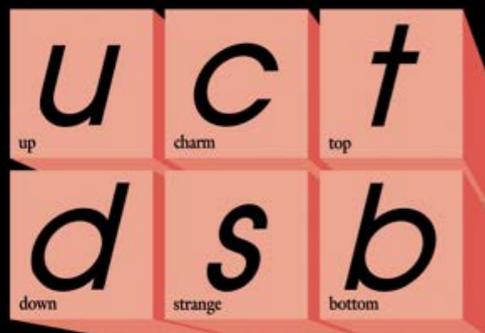
Exploration of a new energy frontier  
Proton-proton collisions at  $E_{CM}$  up to 14 TeV



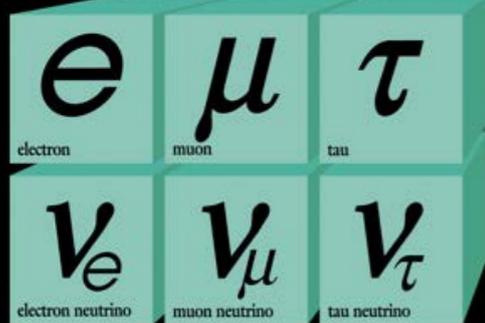
# The discovery of the **Higgs particle** – the most important result from LHC (currently)

4.07.2012

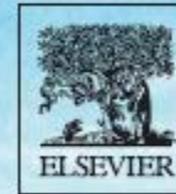
## Quarks



## Forces

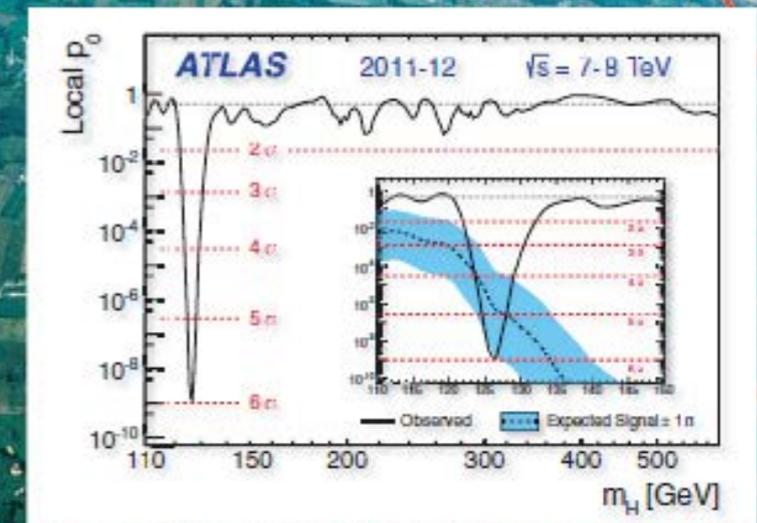
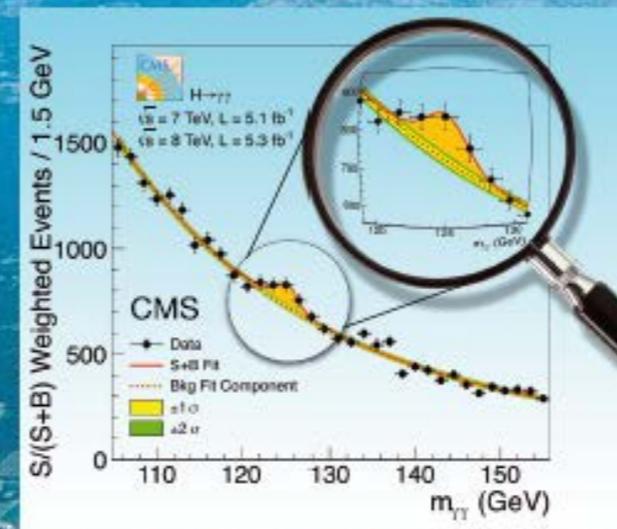


## Leptons



Published:  
Physics Letters B 716,  
17 Sep 2012

# First observations of a new particle in the search for the Standard Model Higgs boson at the LHC





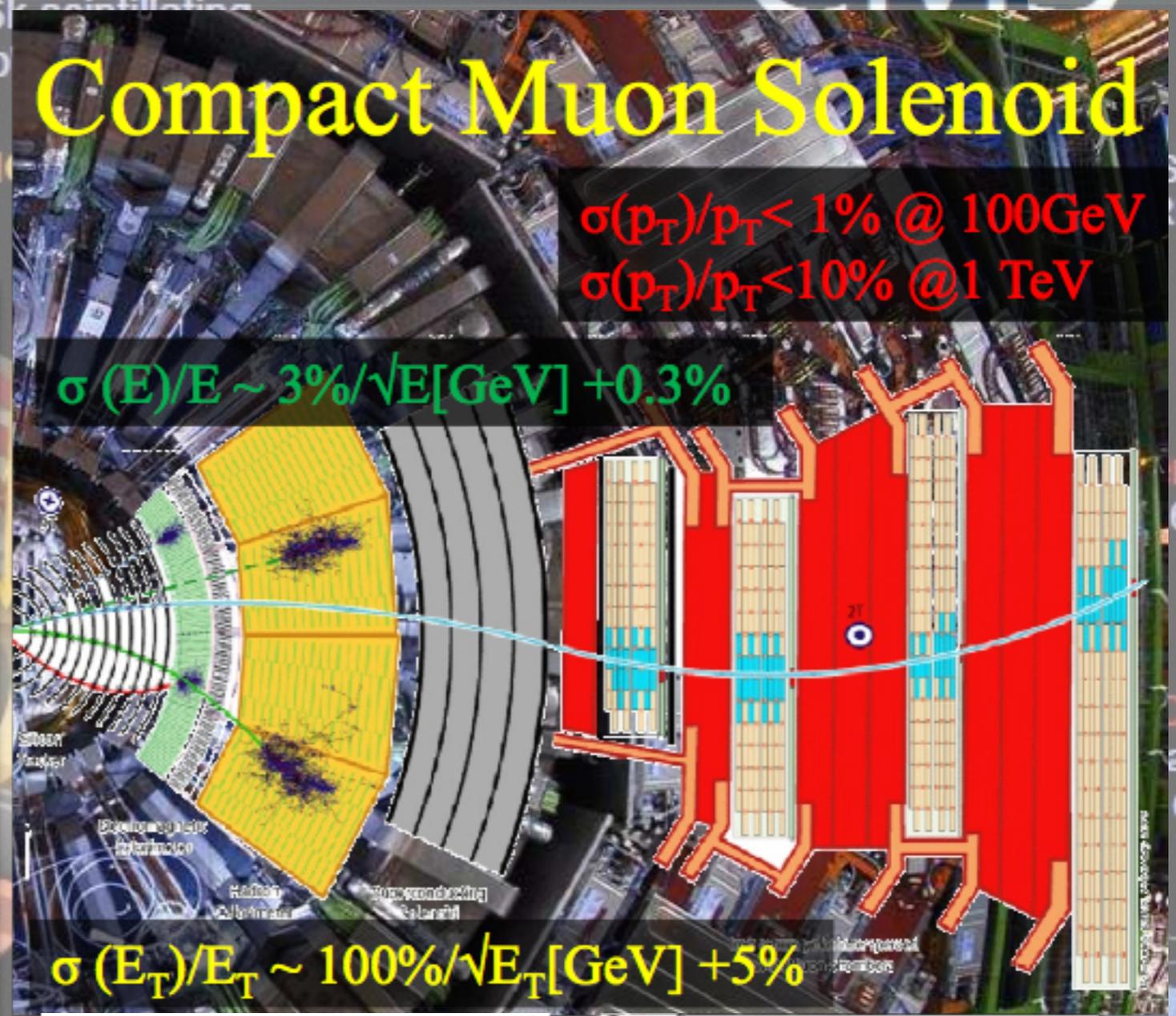
Total weight 14000 t  
 Overall diameter 15 m  
 Overall length 28.7 m

## Compact Muon Solenoid

$\sigma(p_T)/p_T < 1\% @ 100\text{GeV}$   
 $\sigma(p_T)/p_T < 10\% @ 1\text{TeV}$

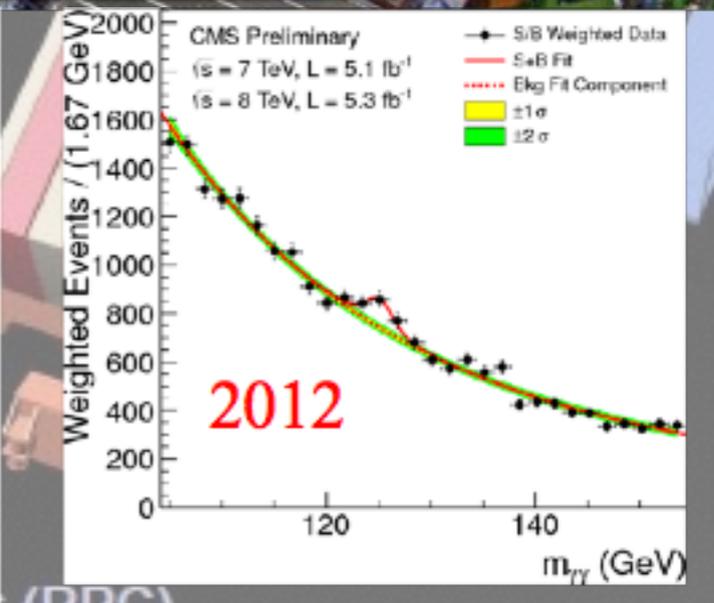
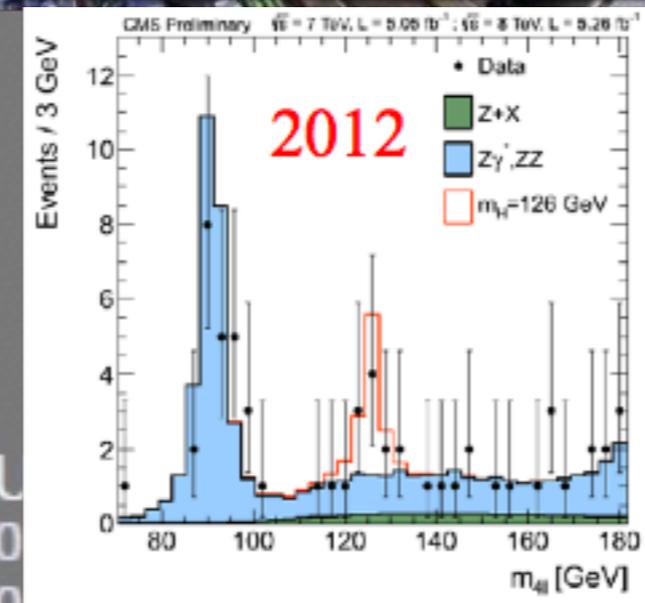
$\sigma(E)/E \sim 3\%/\sqrt{E[\text{GeV}]} + 0.3\%$

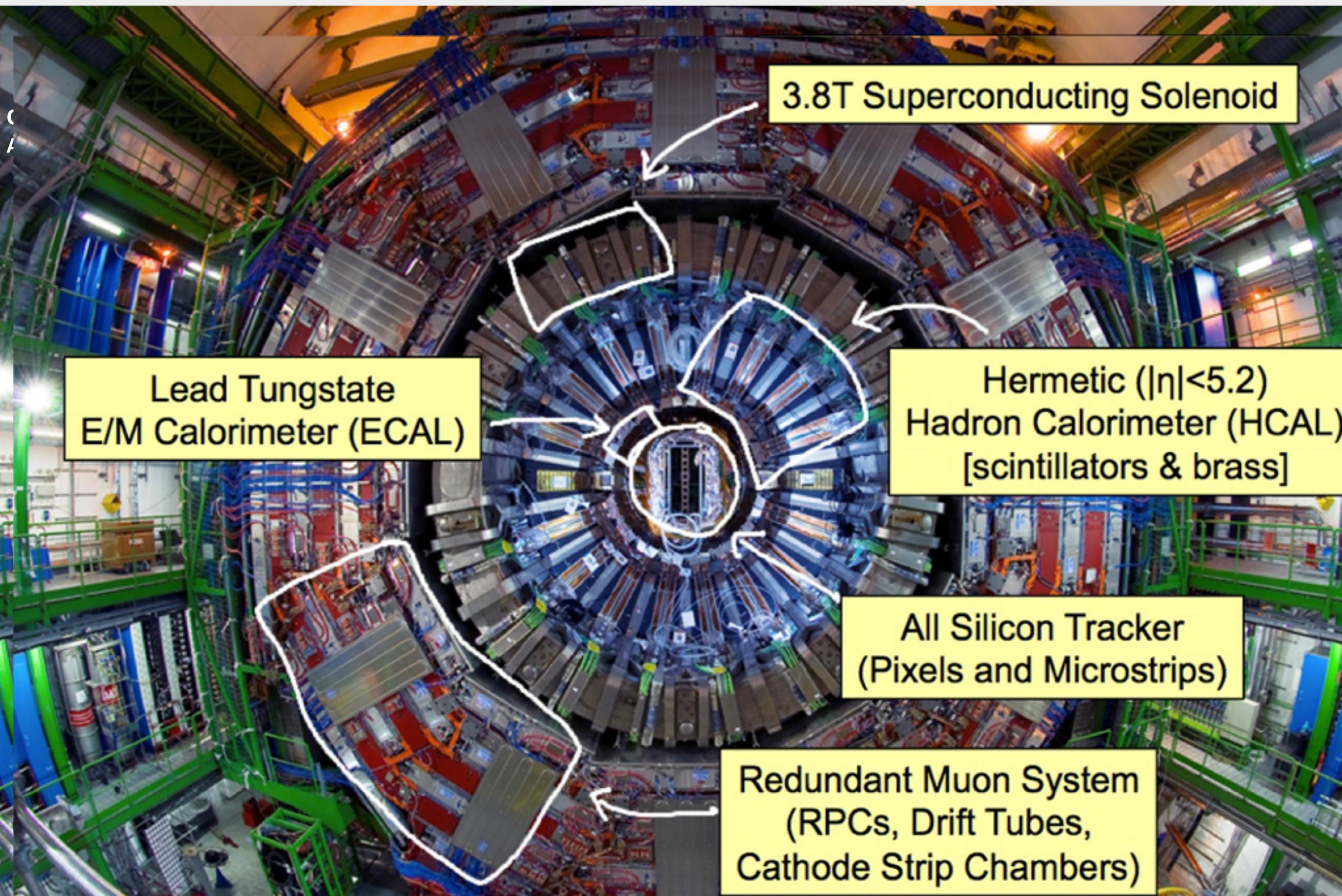
$\sigma(E_T)/E_T \sim 100\%/\sqrt{E_T[\text{GeV}]} + 5\%$



- The design goals of CMS:**
1. A very good and redundant muon system
  2. The best possible ECAL consistent with 1)
  3. A high quality central tracking to achieve 1) and 2)
  4. A financially affordable detector

-3.8T solenoid 13m long, 6m diameter  
 - high eta HCAL coverage  
 -Silicon based inner tracking system  
 supplementing all types of reconstr.  
**Powerful reconstruction of:**  
 **$\mu$ ,  $e/\gamma$ ,  $\tau$ -jets, jets, MET**  
 (+tracks, vertices)





3.8T Superconducting Solenoid

Lead Tungstate  
E/M Calorimeter (ECAL)

Hermetic ( $|\eta| < 5.2$ )  
Hadron Calorimeter (HCAL)  
[scintillators & brass]

All Silicon Tracker  
(Pixels and Microstrips)

Redundant Muon System  
(RPCs, Drift Tubes,  
Cathode Strip Chambers)

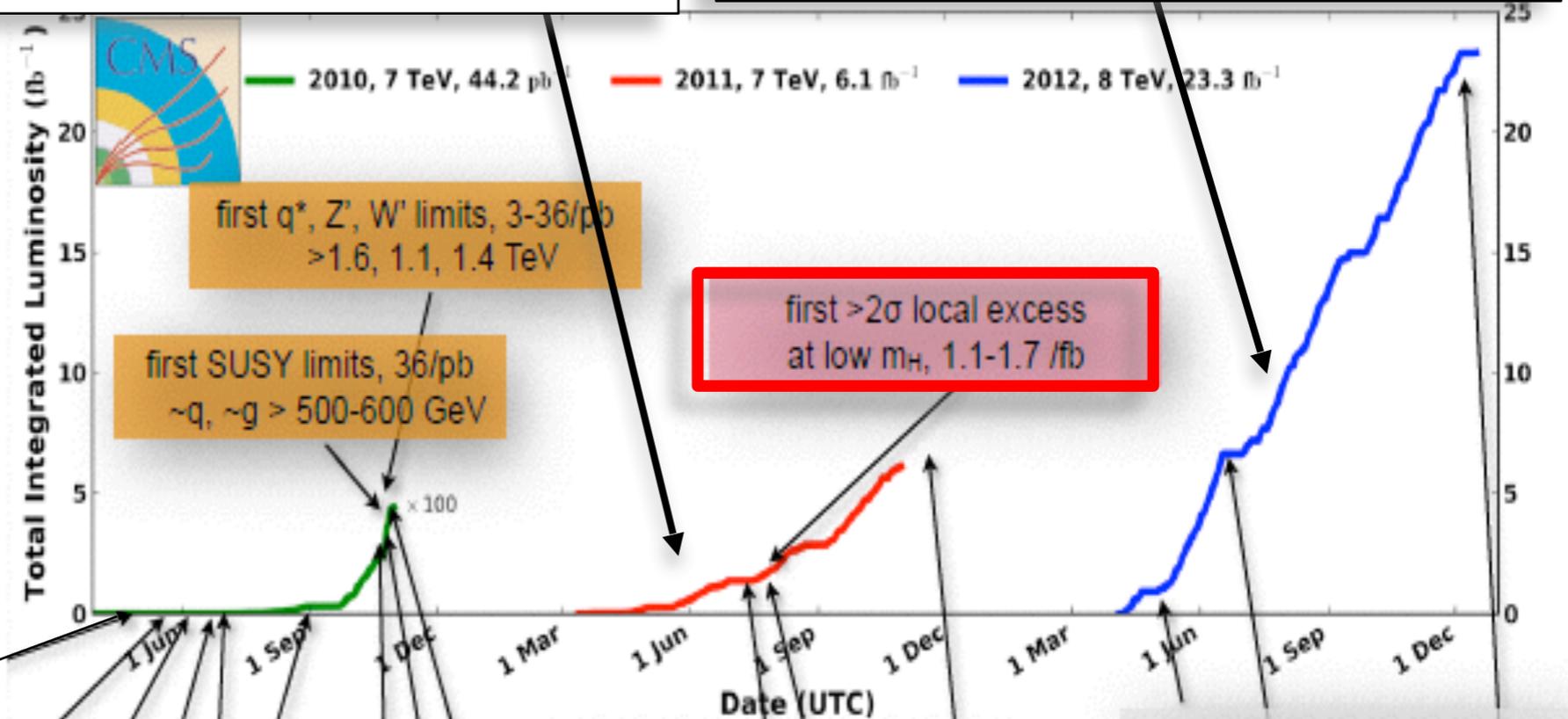


Plenty of barrel muons in online display!

100 Khz barrel muons (all pt)

2009 running:

- Hard to see anything apart from min bias in the displays.
- Serious analysis to find muons in the barrel.



What a run!

first MinBias / UE studies, particle multiplicities

first incl. b x-section, 8/nb δ ~ 15 %

first incl. jet x-section, PF jets 60/nb δ ~ 20-30%

first incl. W/Z x-sections, 200/nb δ ~ 4-6%, +11% lumi

first incl. J/ψ x-section, 100/nb δ ~ 20%

first top xsec, 3/pb δ ~ 40%

first single top xsec, t-chan., 36/pb δ ~ 36%

first m<sub>top</sub>, 36/pb Δ ~ 6.5 GeV

first WW xsec, 36/pb δ ~ 40% first limit on HWW

first ZZ xsec, 1.1 /fb δ ~ 40%

going more differential, e.g. Z/W + j,b,c

first significant limit on B<sub>s</sub> → μμ, BR < 1.9 × 10<sup>-8</sup>

first particle discovered by CMS:  $\Xi_b$

BSM searches continue, limits pushed

a new boson is announced, 5 /fb

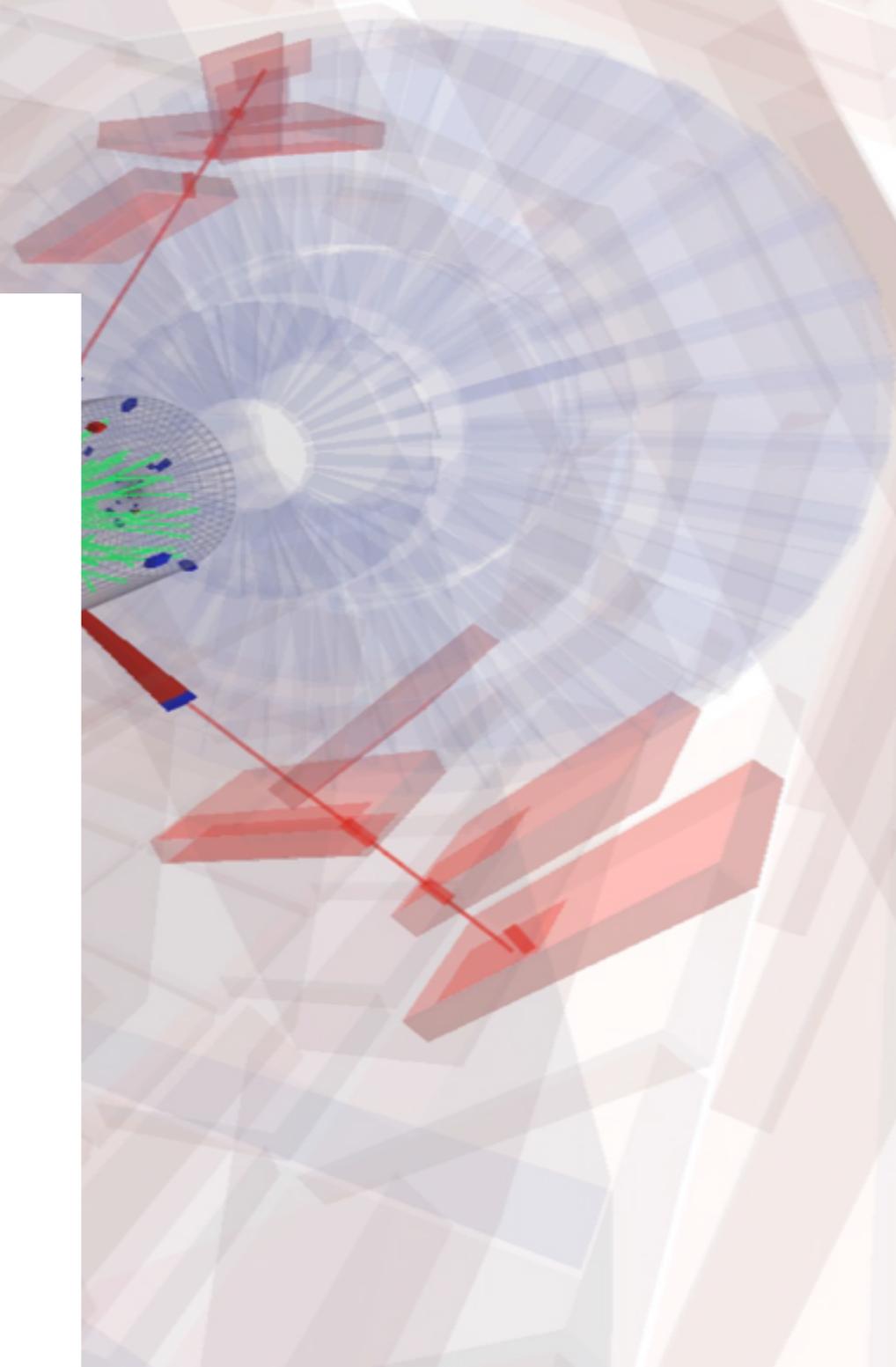


first spin parity analysis of the boson, 17 /fb

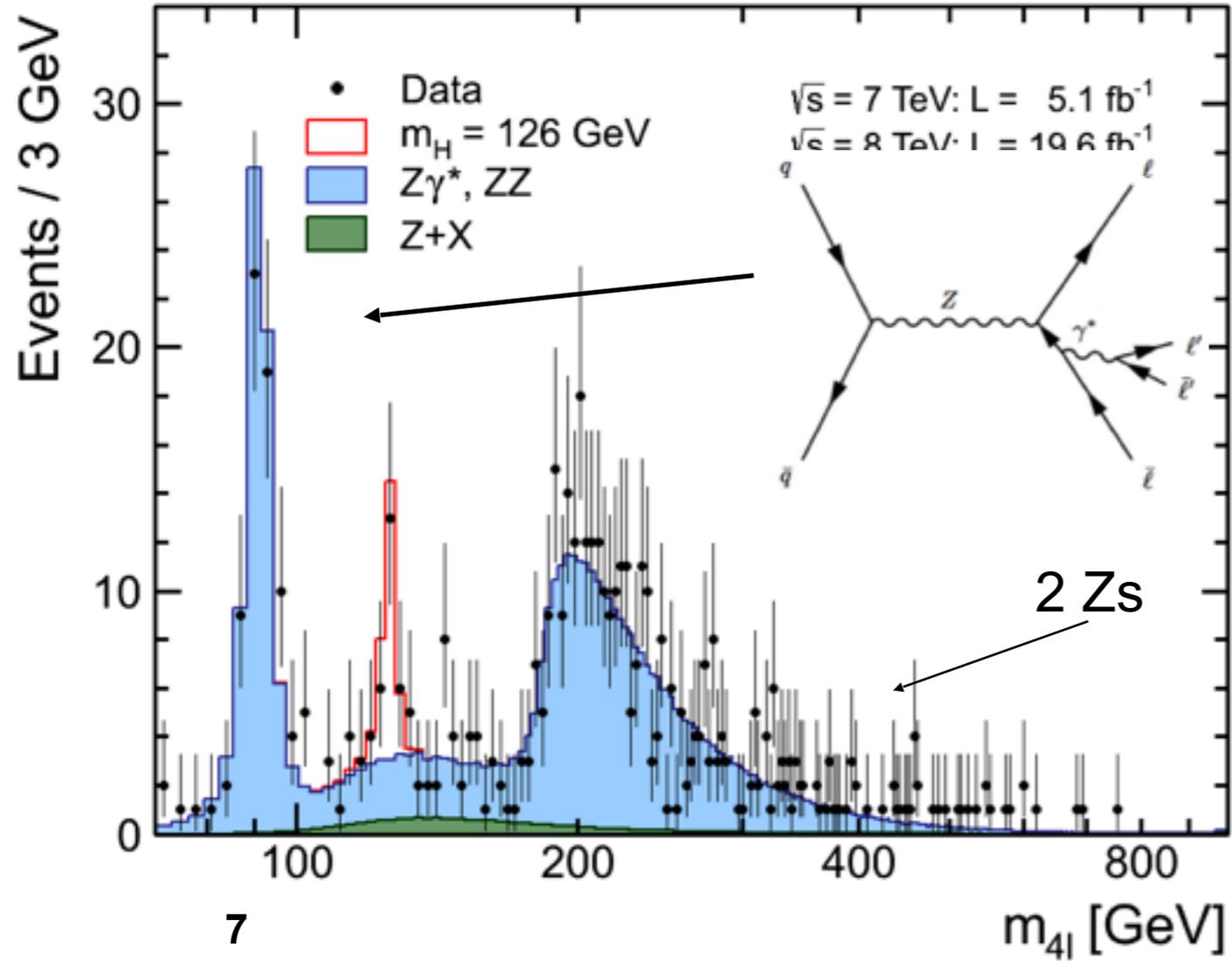
δ .. relative uncert

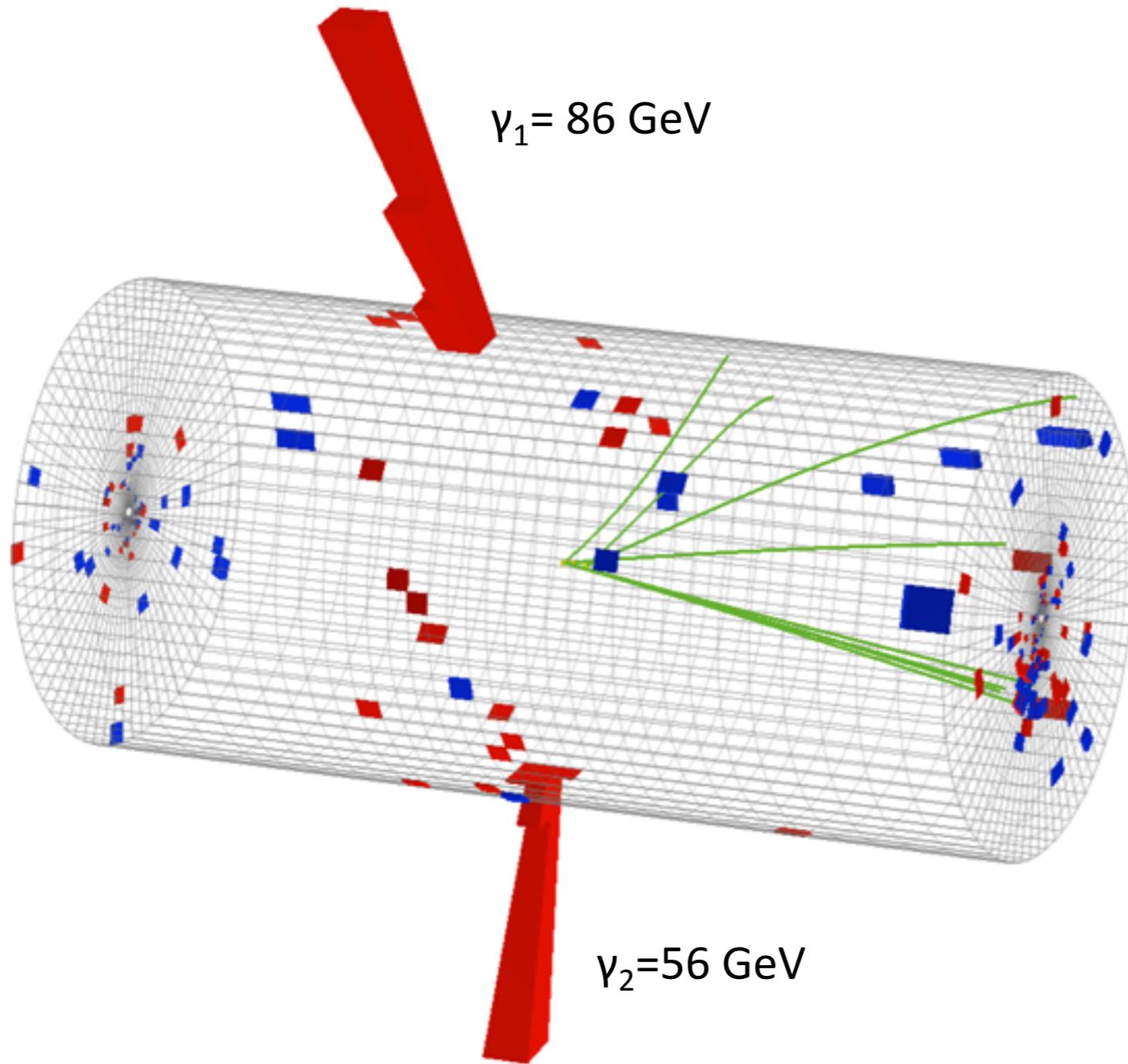
Δ .. absolute uncert.

G. Dissertori

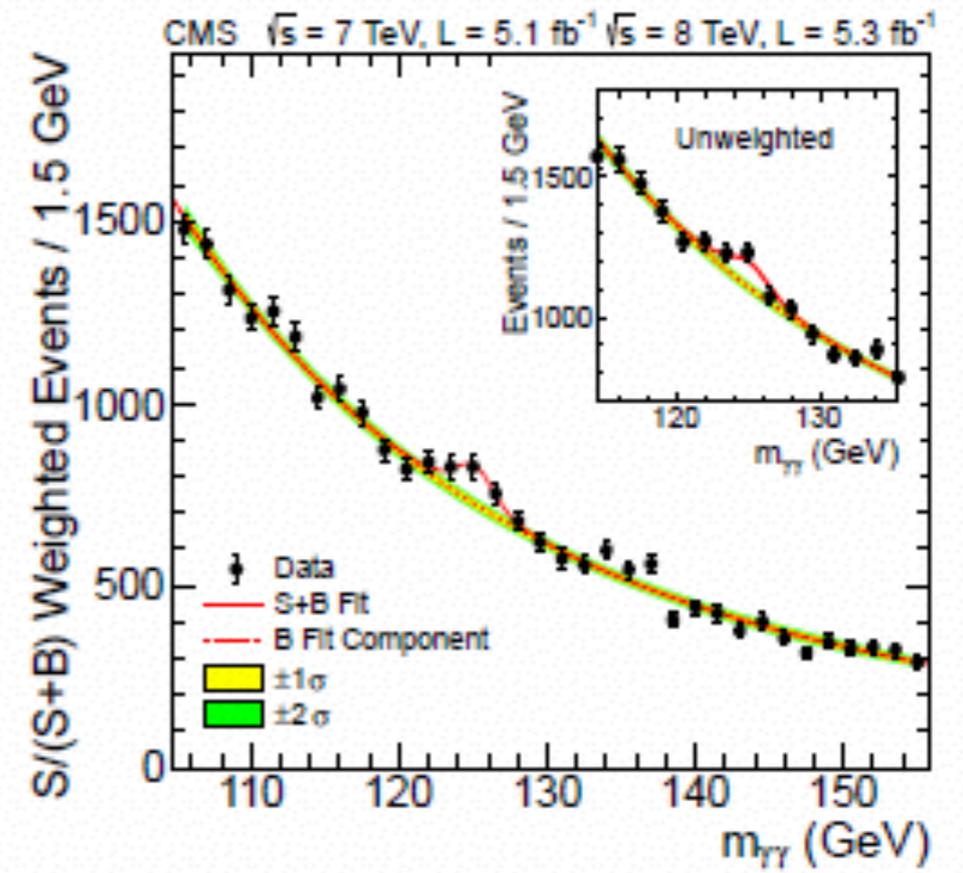


CMS preliminary





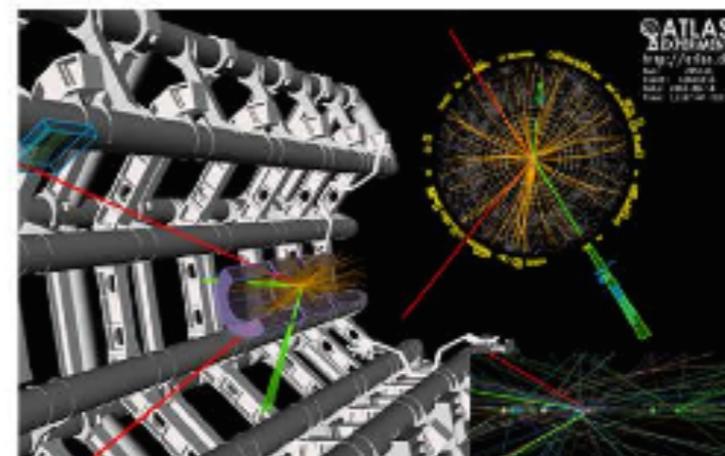
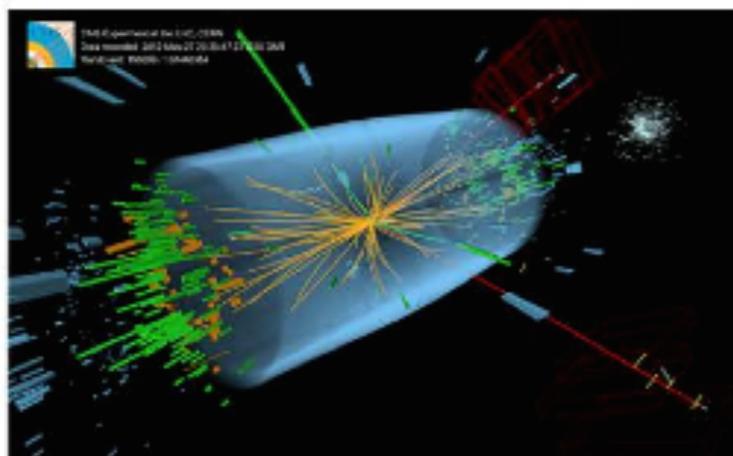
CMS Collaboration,  
*Phys. Lett. B716 (2012) 30-61*



# The Nobel Prize in Physics 2013



The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider



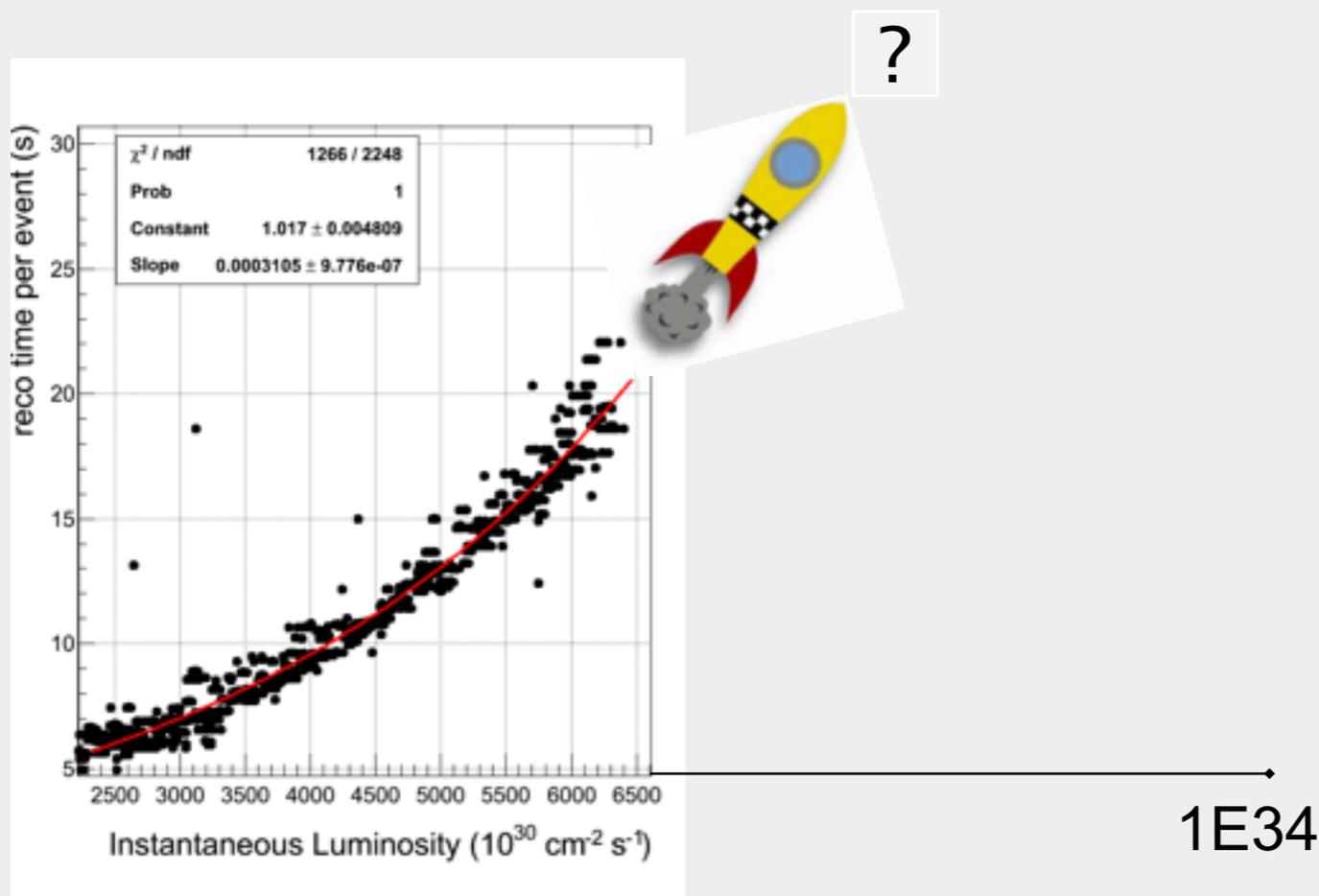
## Reconstructed events

20 billion simulated events  
12 billion data events

## Data volume

More than 25PB moved to Tier-1s  
70PB moved to Tier-2s

- Improvements in the reconstruction code to cope with pile up
- Reconstruction time per event reduced by maintaining the physics performance.
  - Non-linear with PU → explodes



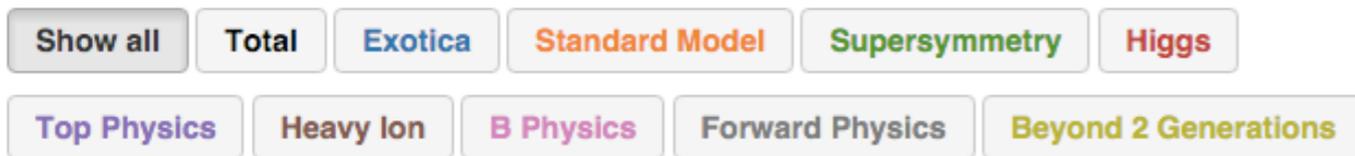
Quite a challenge:  
All things equal,  
2015 computing  
needs increase x10



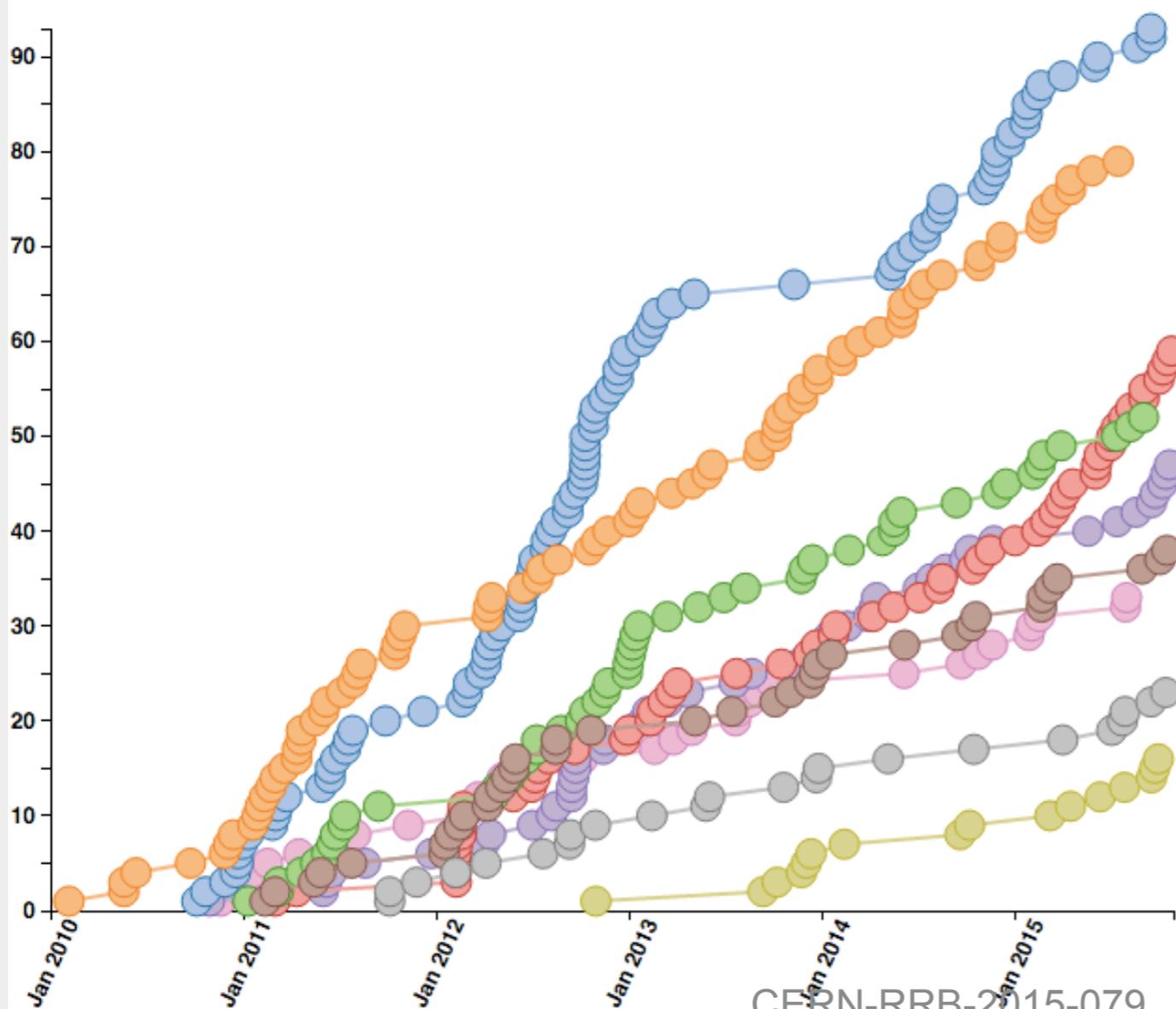
Event ID: 16992111 / 2295  
CMS Experiment at LHC, CERN  
Data recorded: Mon May 28 01:16:20 2012 CEST  
Run/Event: 195099 / 35438125  
Lumi section: 65  
Orbit/Crossing: 16992111 / 2295

This starts being a not so easy environment...  
Conditions in Run1 could be similar to these.

2012 Data at 8 TeV. Event with:  
Raw  $\Sigma ET \sim 2$  TeV  
14 jets with  $ET > 40$  GeV  
Estimated pile up  $\sim 50$



439 papers submitted as of 2015-10-22



439 papers submitted:  
 +23 CRAFT based  
 +48 ready for CWR or later

In review process (ready for pre-app or later): 60

36 Run 1 analyses in "Analysis WG"

37 Run 2 analyses in "Analysis WG"

1 paper on 13 TeV accepted  
 1 submitted  
 1 in Final Reading

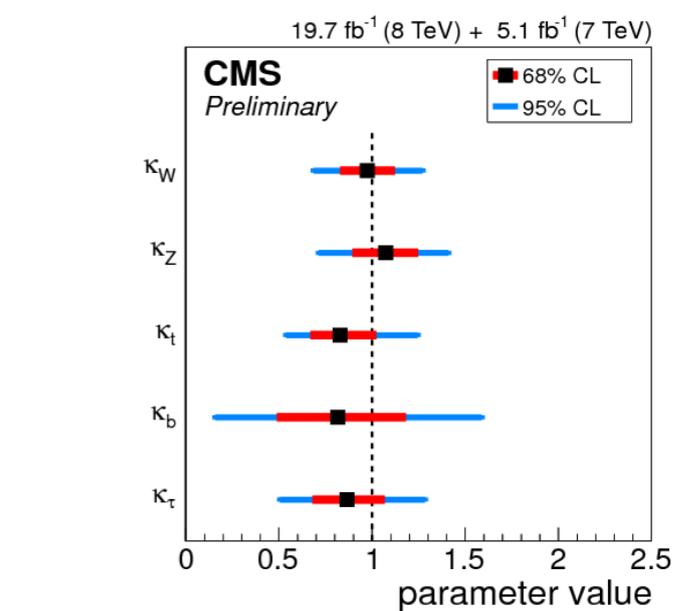
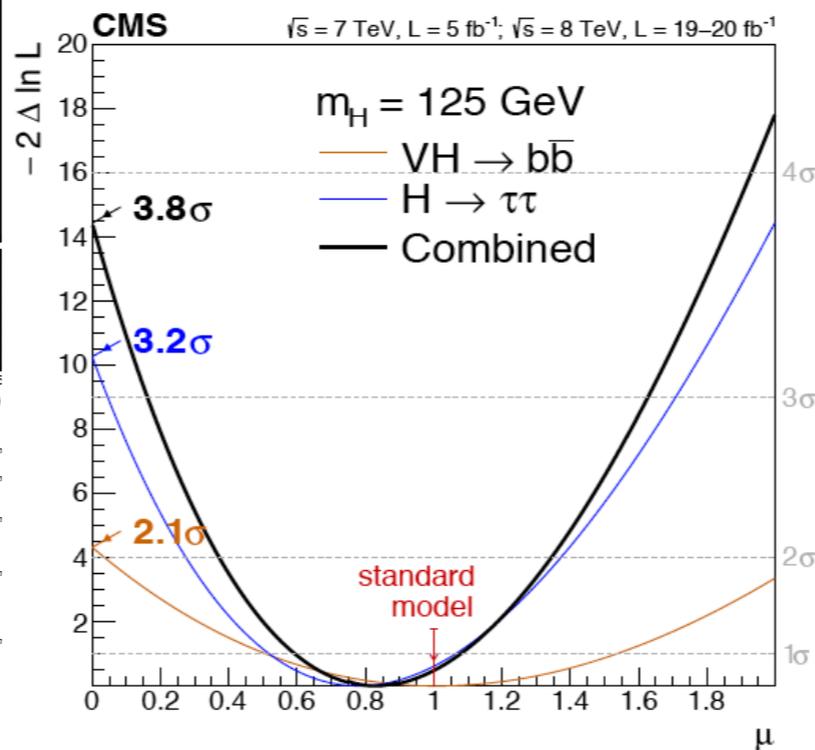
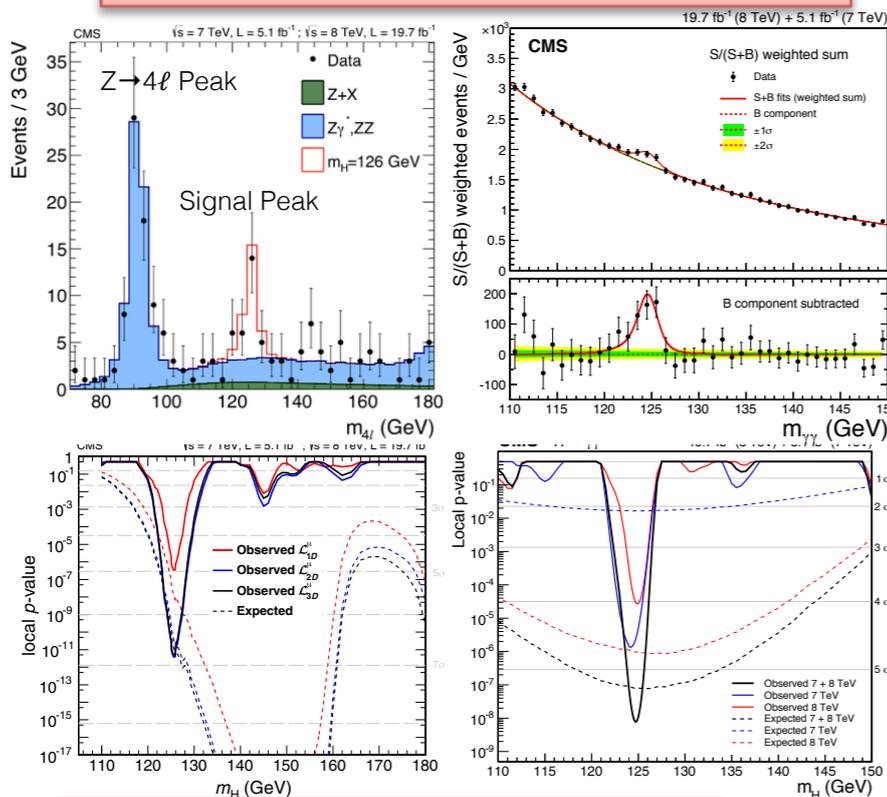


# The new boson: looks like the expected one

**Significance: huge**

**$H \rightarrow \tau\tau + H \rightarrow bb$**

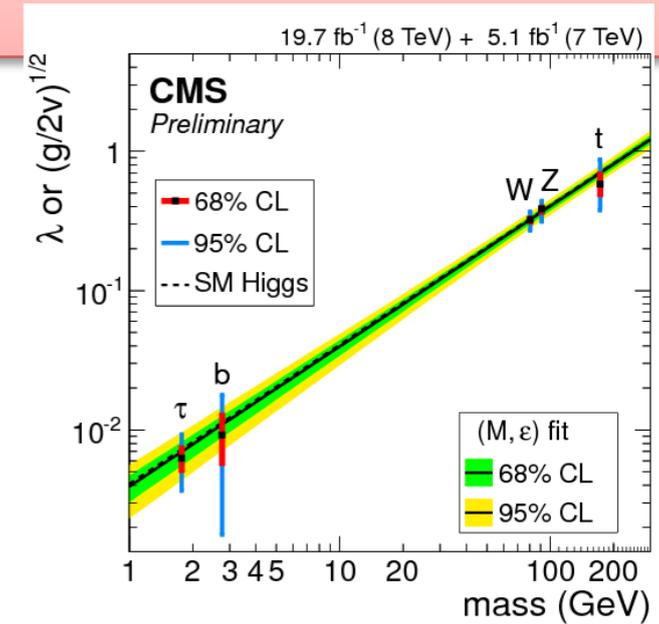
**Couplings wrt SM**



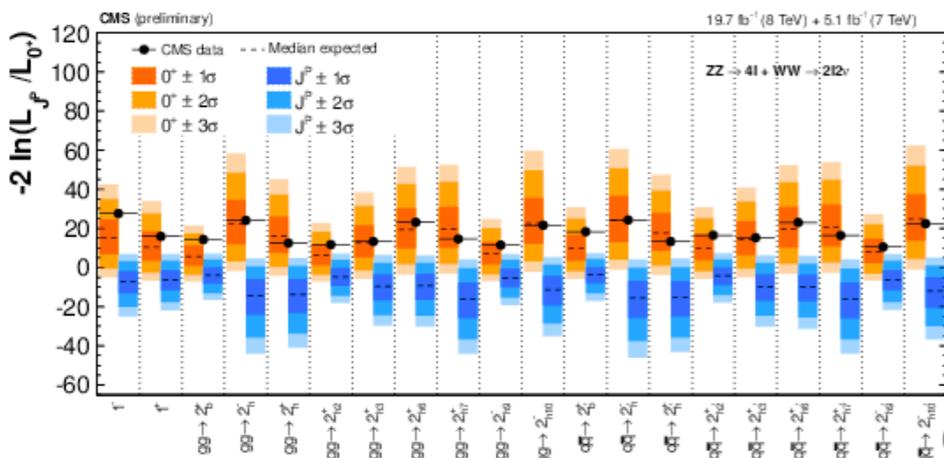
**Spin-parity:  $0^+$   
As expected by SM**

Significance	Exp	Obs
CMS ( $\tau\tau$ )	$3.4 \sigma$	$3.2 \sigma$
CMS (bb)	$2.1 \sigma$	$2.1 \sigma$

**$g \sim m^2$  non-universality  
As expected by SM**



**Put simply:  
it couples to  
fermions**



# CMS detector for Run2

Improvements during  
Long Shut Down LS1

Tracker / Pixel:  
Cold Operation

Tracker:

~1 m<sup>2</sup> Pixels (66M channels)

~200 m<sup>2</sup> Si microstrips (9.6M channels)

Iron Yoke

4th muon station

4 stations of  
muon detectors

new Beam Pipe

new Luminosity  
telescopes

3.8 T Solenoid

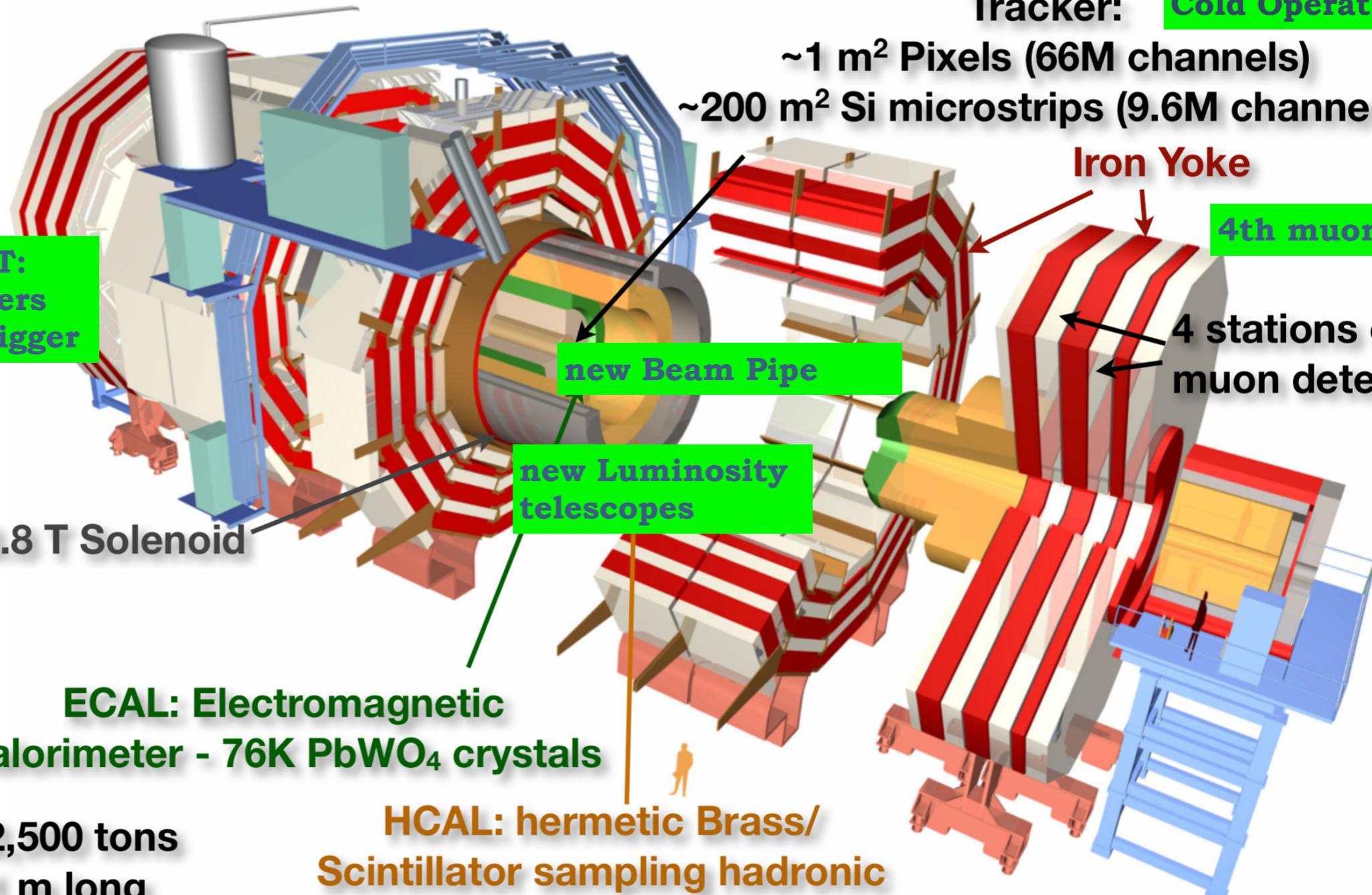
ECAL: Electromagnetic  
calorimeter - 76K PbWO<sub>4</sub> crystals

12,500 tons  
21 m long  
15 m diameter

HCAL: hermetic Brass/  
Scintillator sampling hadronic  
calorimeter

HCAL new photosensors

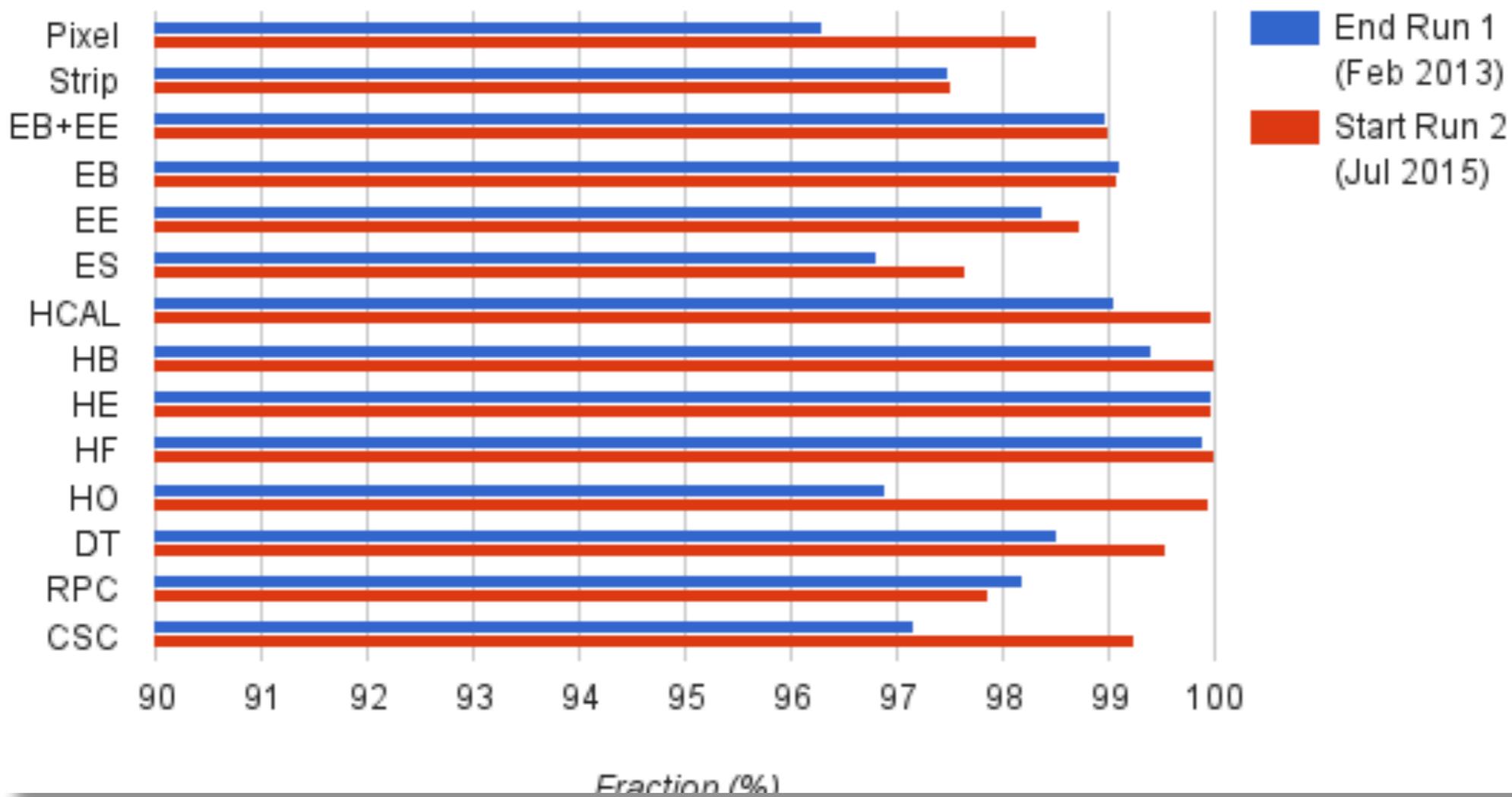
DAQ and HLT:  
New computers  
Improved Trigger





# Run II: Detector & SW in great shape

Active Detector Fraction Run 1 to Run 2



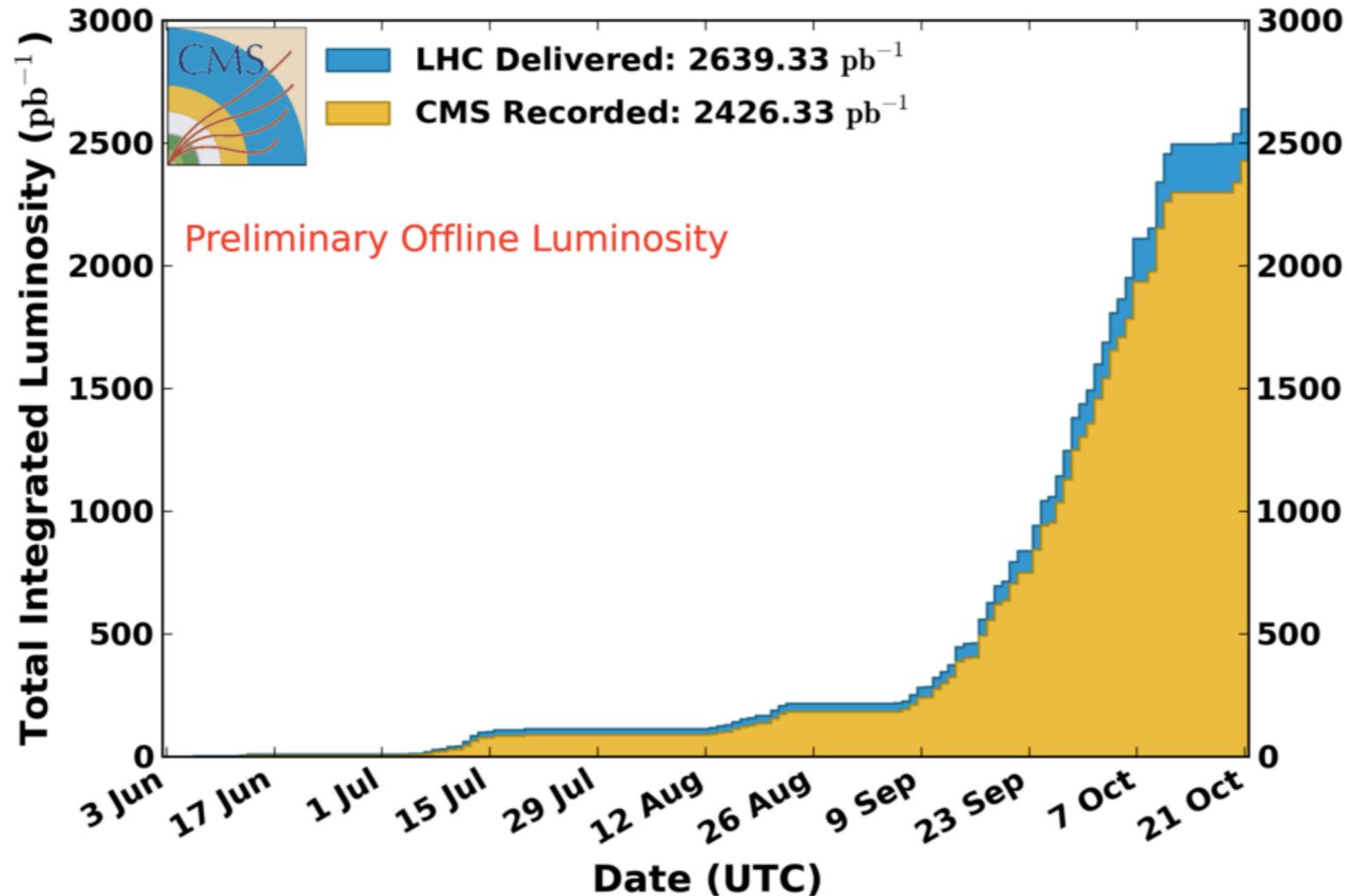
Active channel fraction higher than in Run I



# Run II: data taking

**CMS Integrated Luminosity, pp, 2015,  $\sqrt{s} = 13$  TeV**

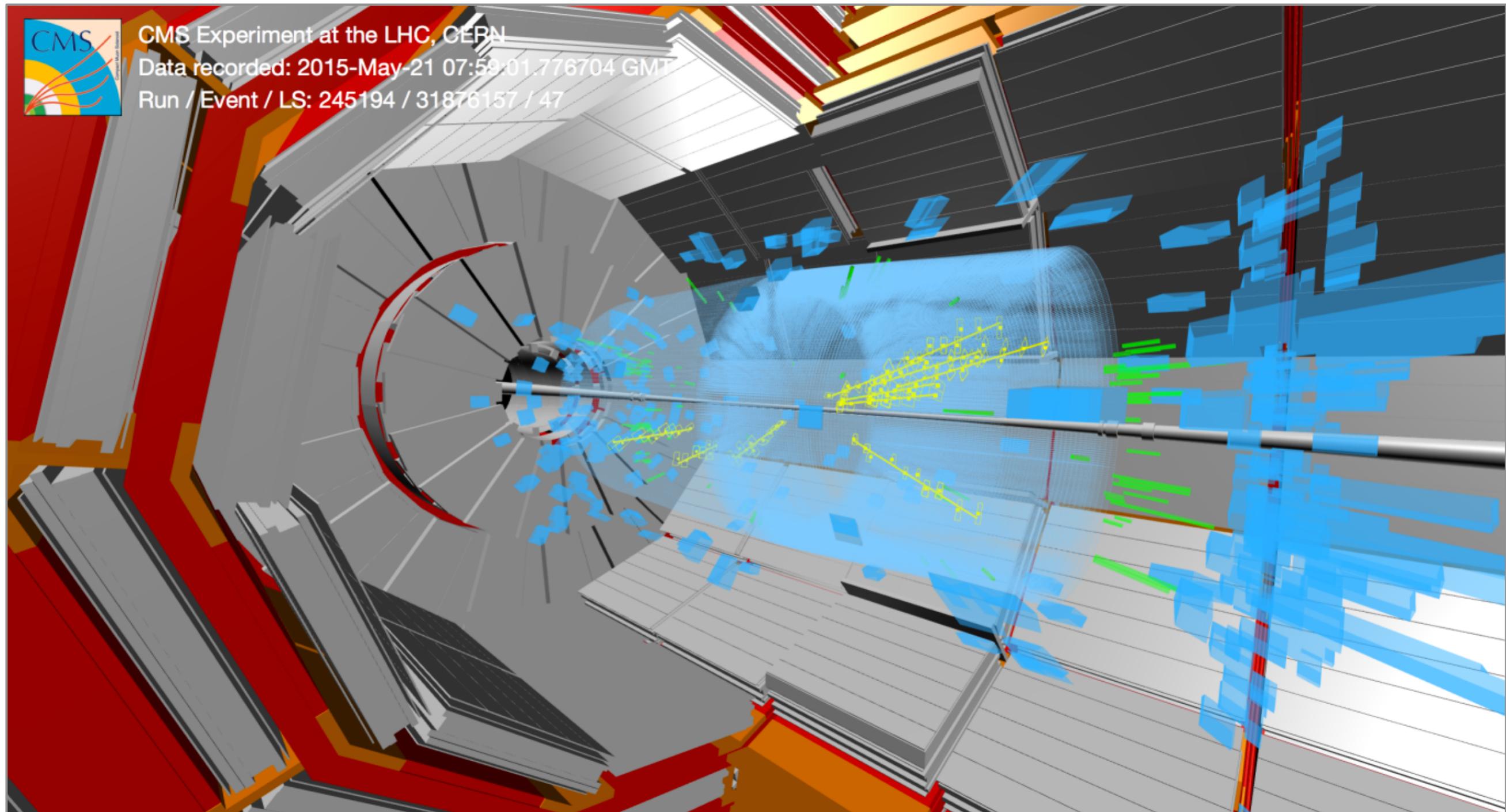
Data included from 2015-06-03 08:41 to 2015-10-21 09:53 UTC



Overall data taking efficiency >92%

Of note: we logged data@10 KHz during special CMS-TOTEM run

# First Physics collision @ 13 TeV





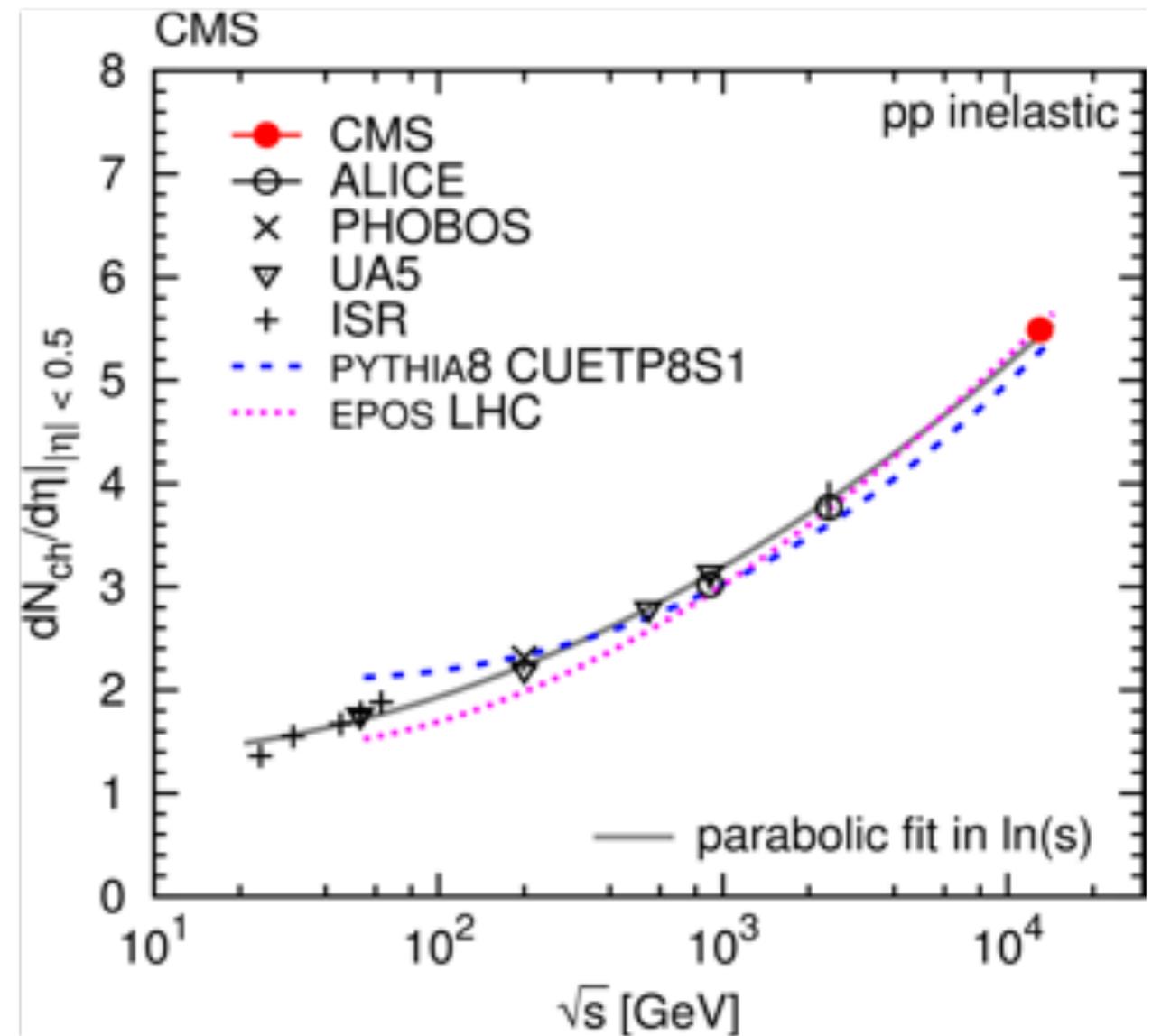
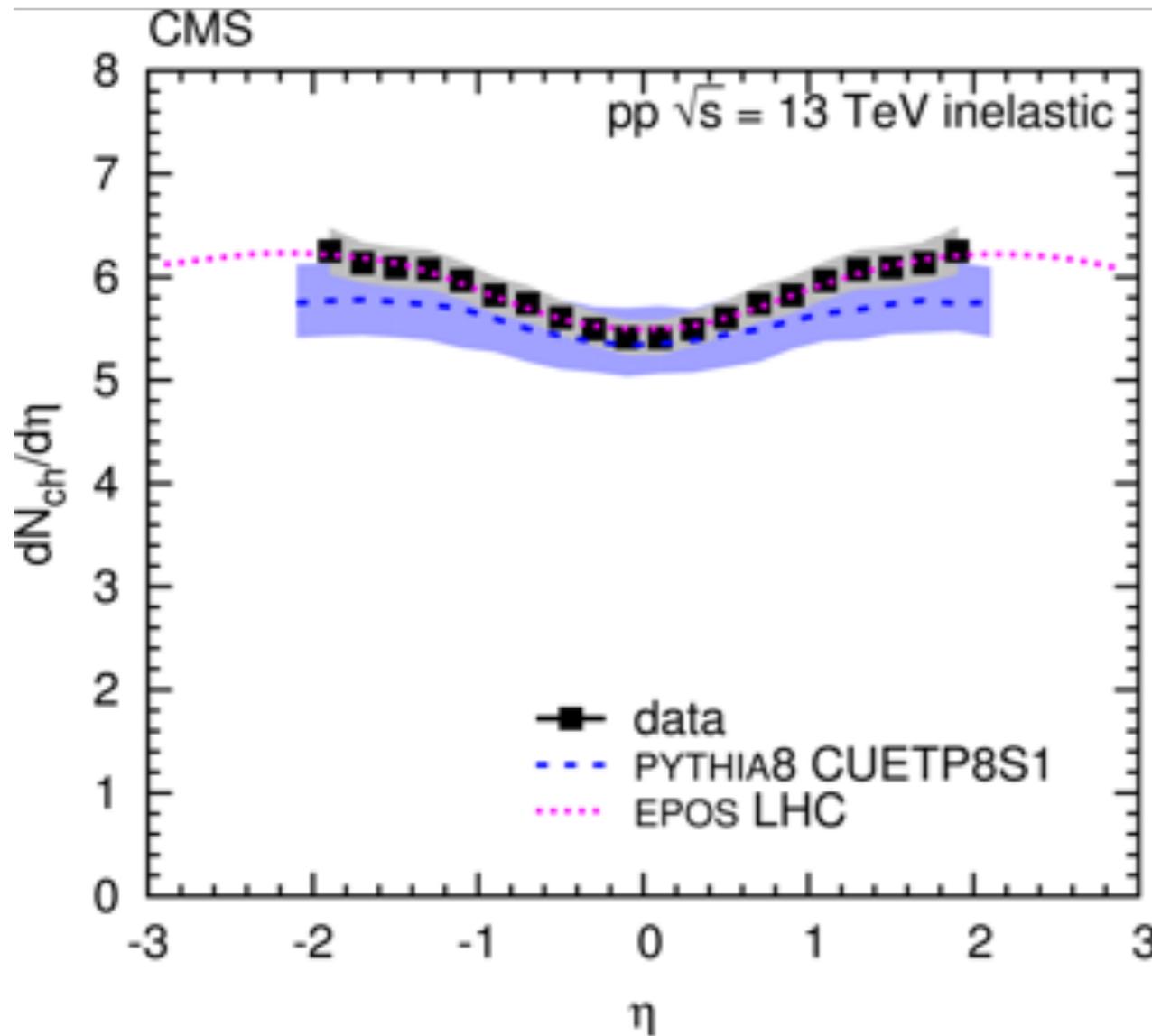
# First LHC publication

Lack of B field has not prevented us from exploiting the first runs taken at low luminosity

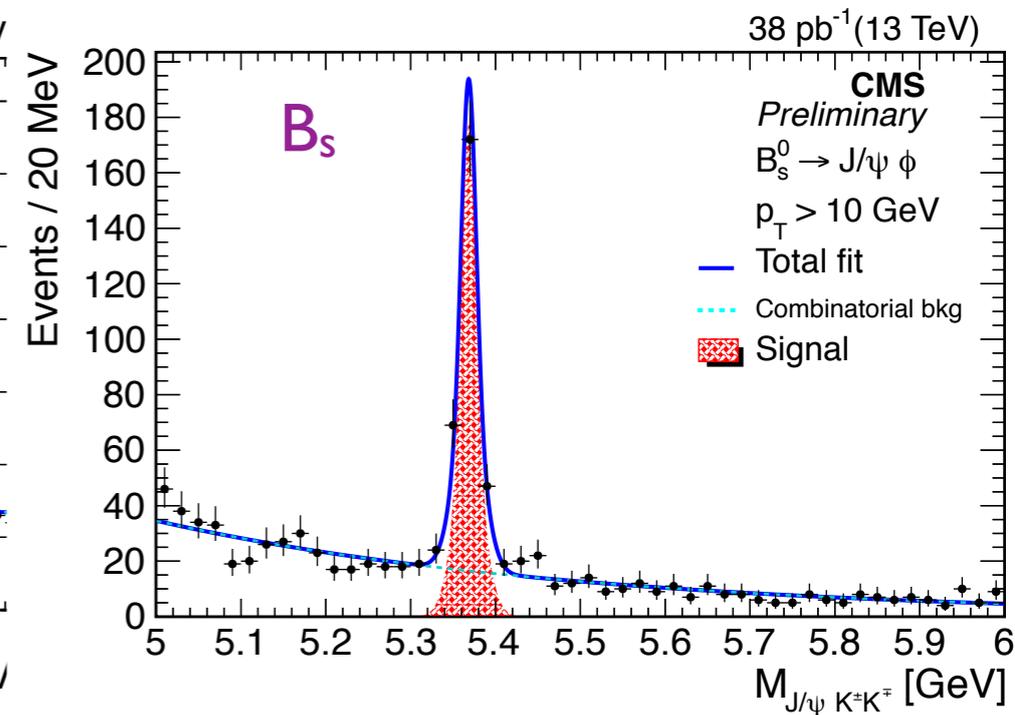
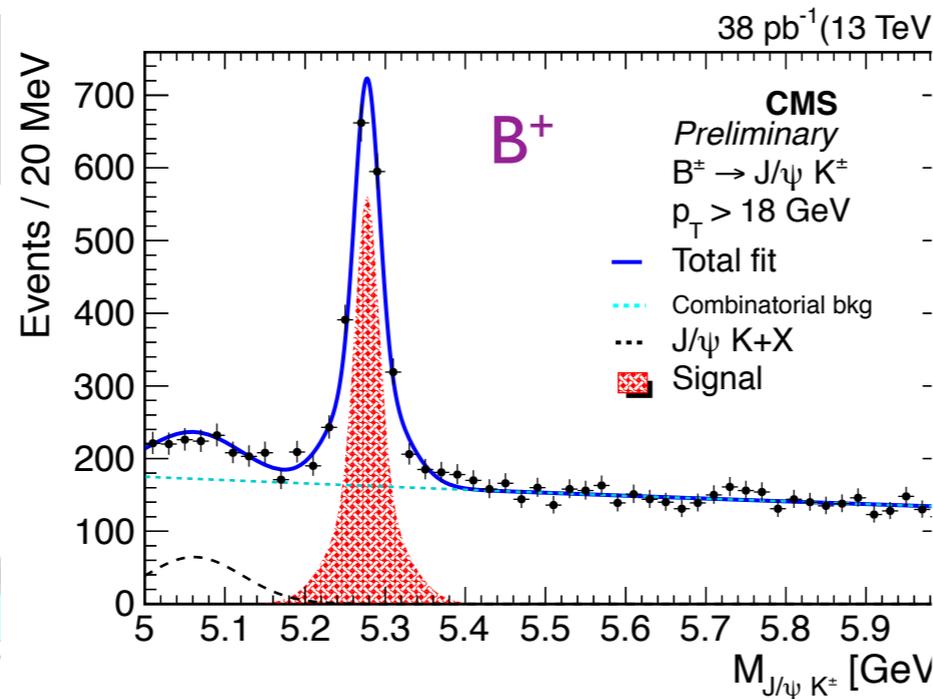
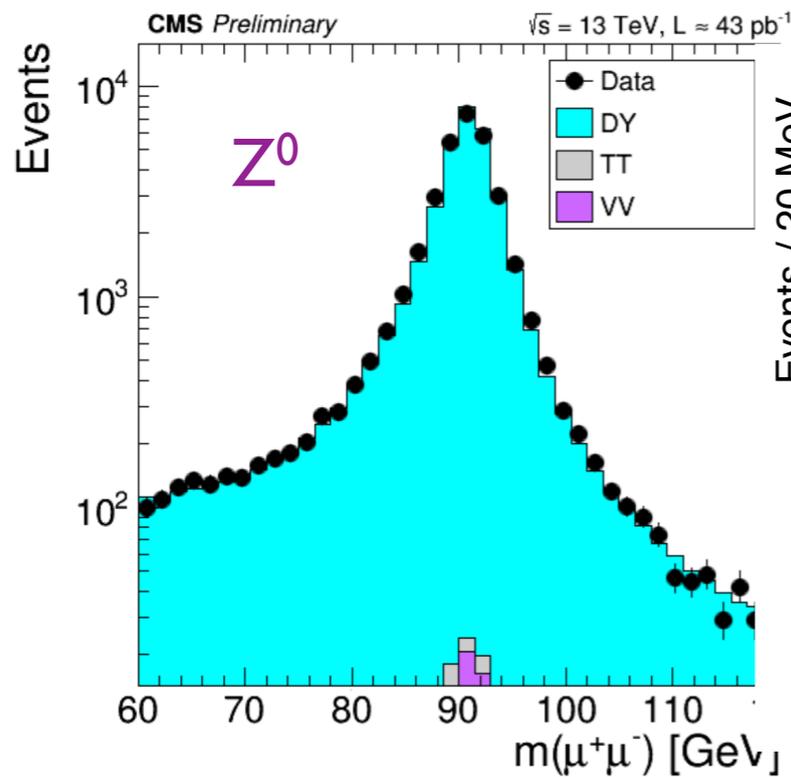
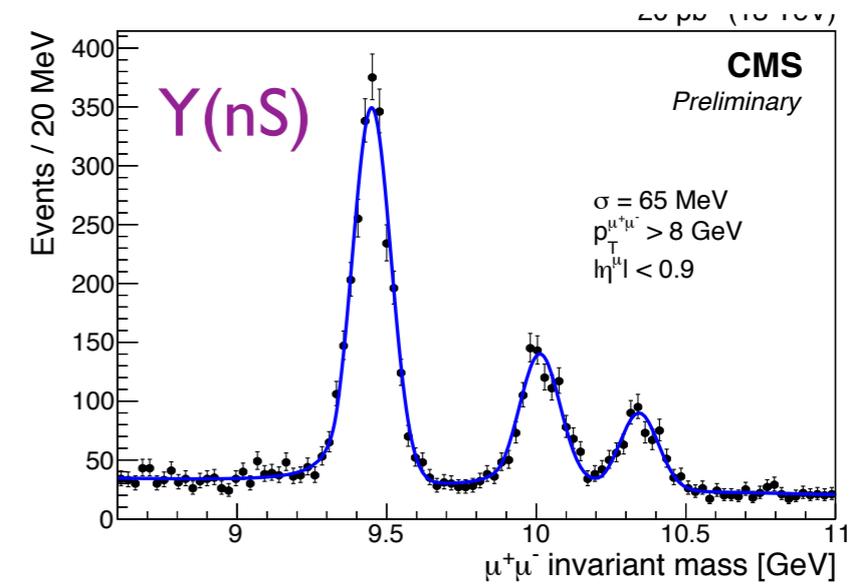
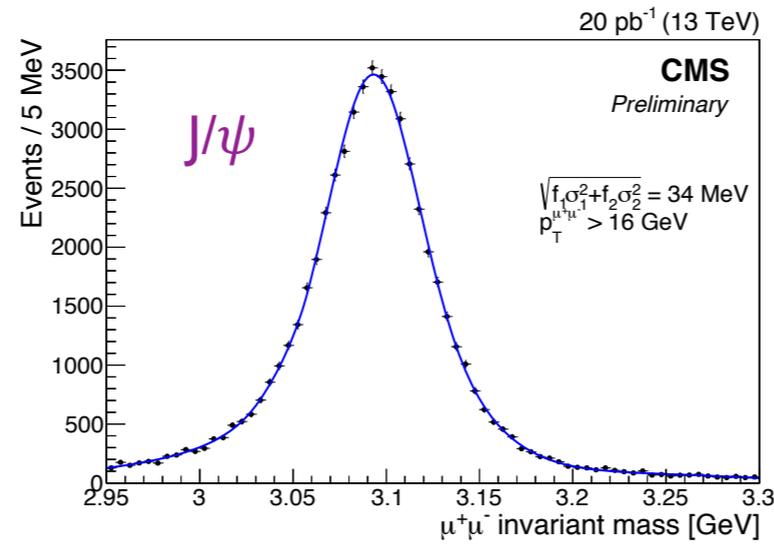
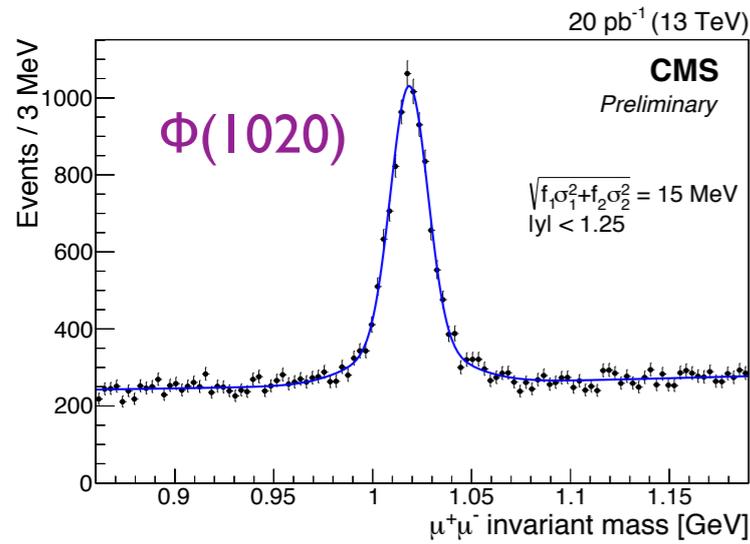
Submitted to PLB

<http://arxiv.org/abs/1507.05915>

$$dN_{ch}/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01 \text{ (stat)} \pm 0.17 \text{ (syst)}$$

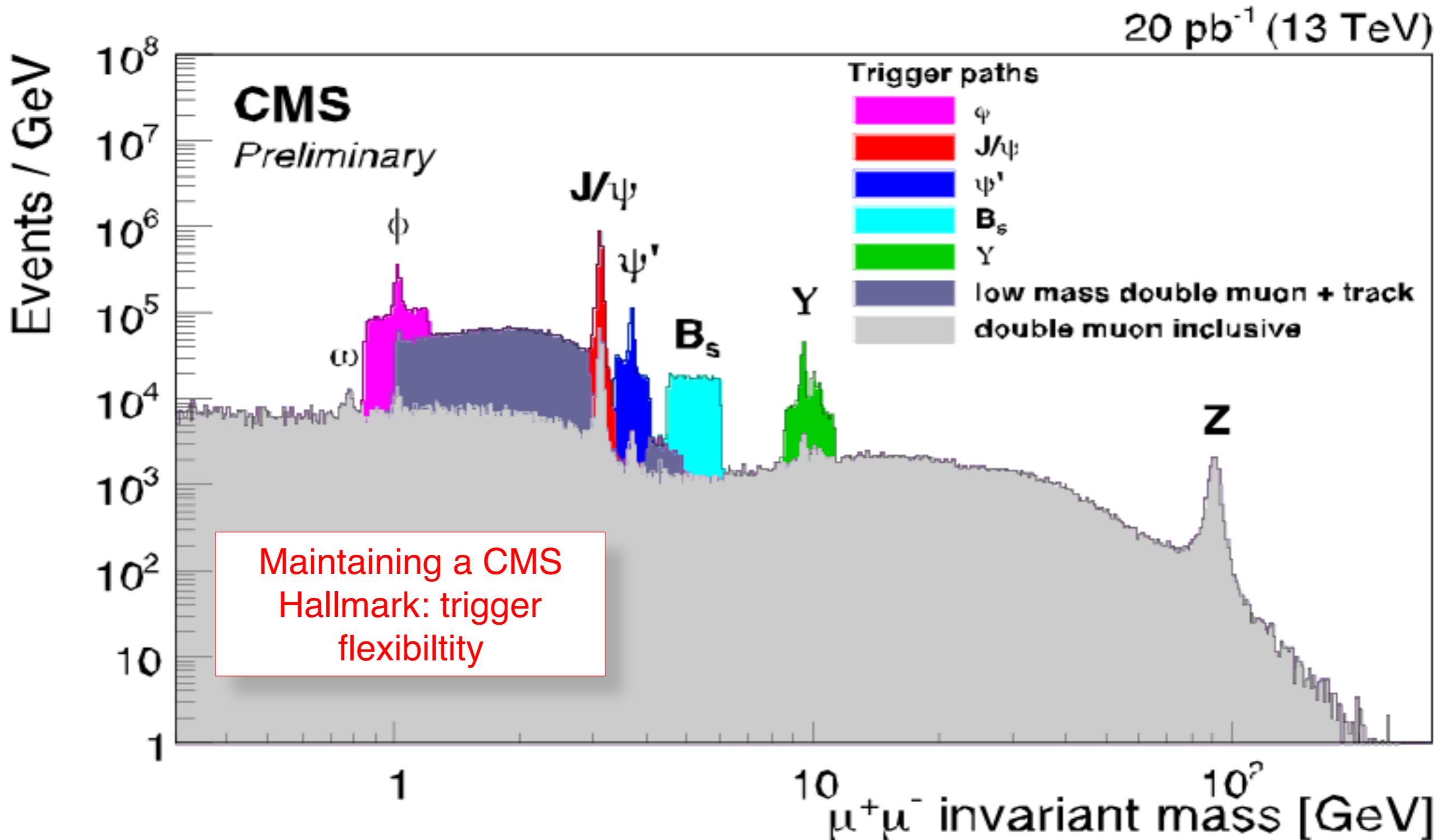


# Di-muon spectroscopy: standard candles resonances and first B mesons



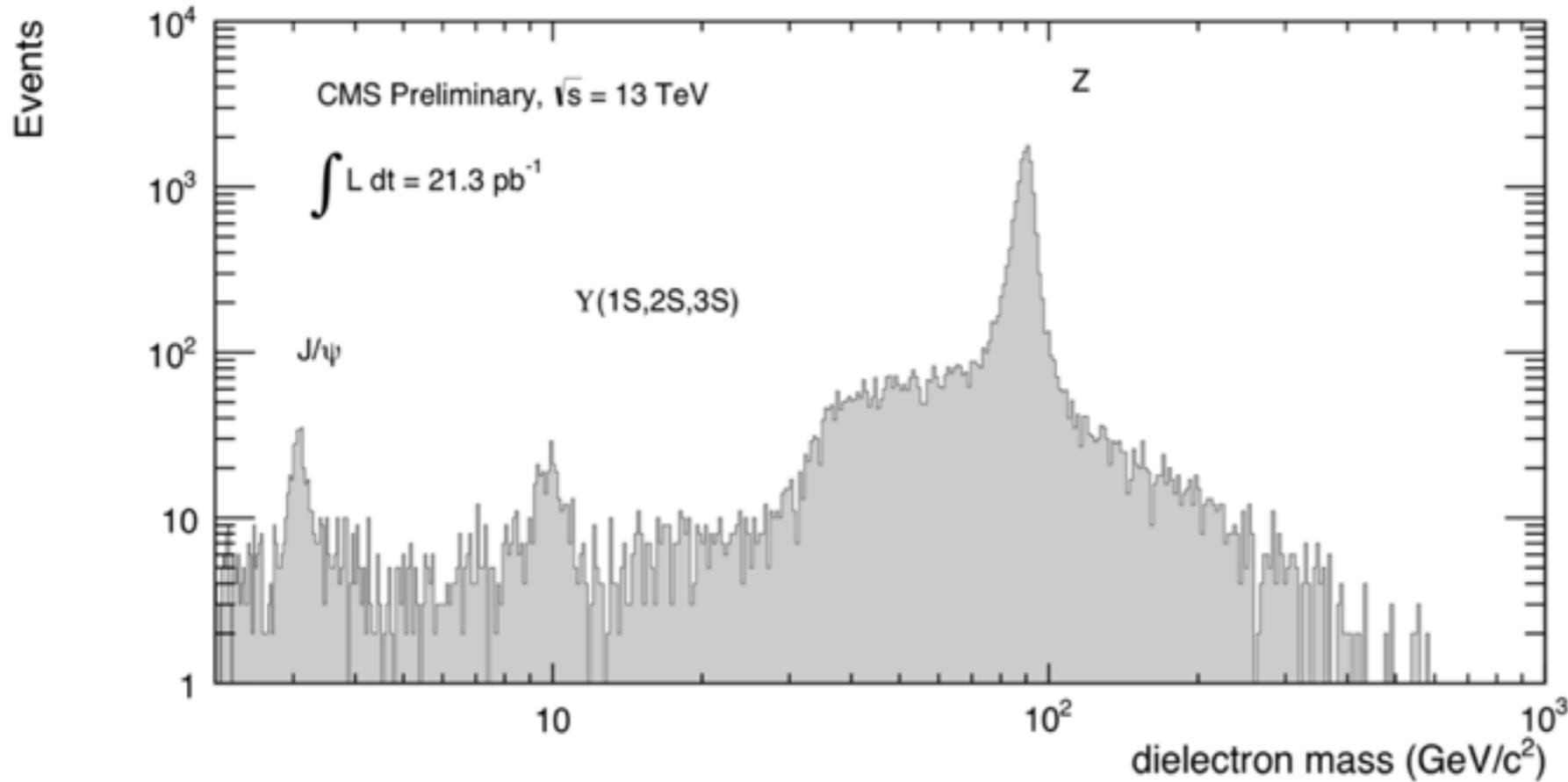


# Run II performance: Di-muon spectroscopy, 13 TeV



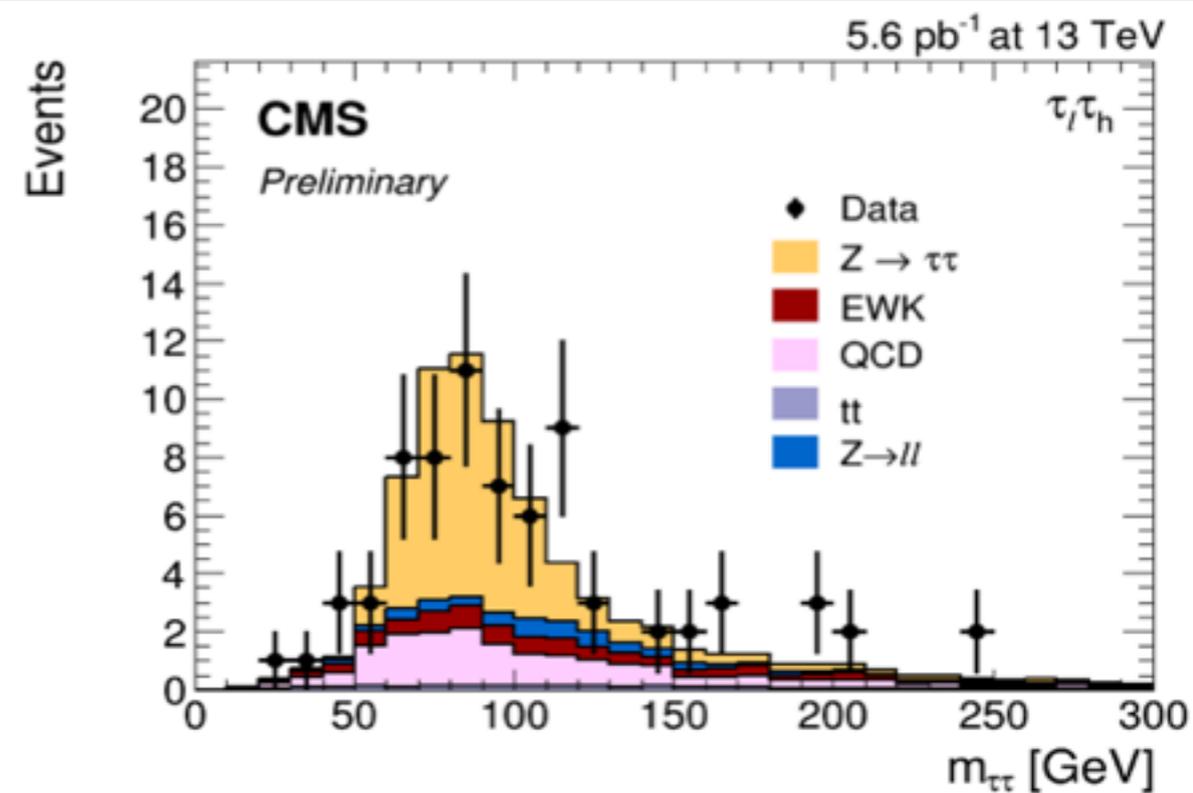


# ...and electrons and taus



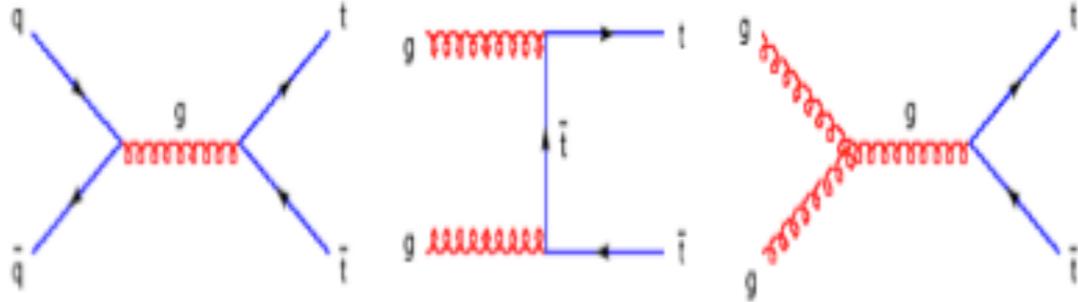
Di-electrons

Di-taus





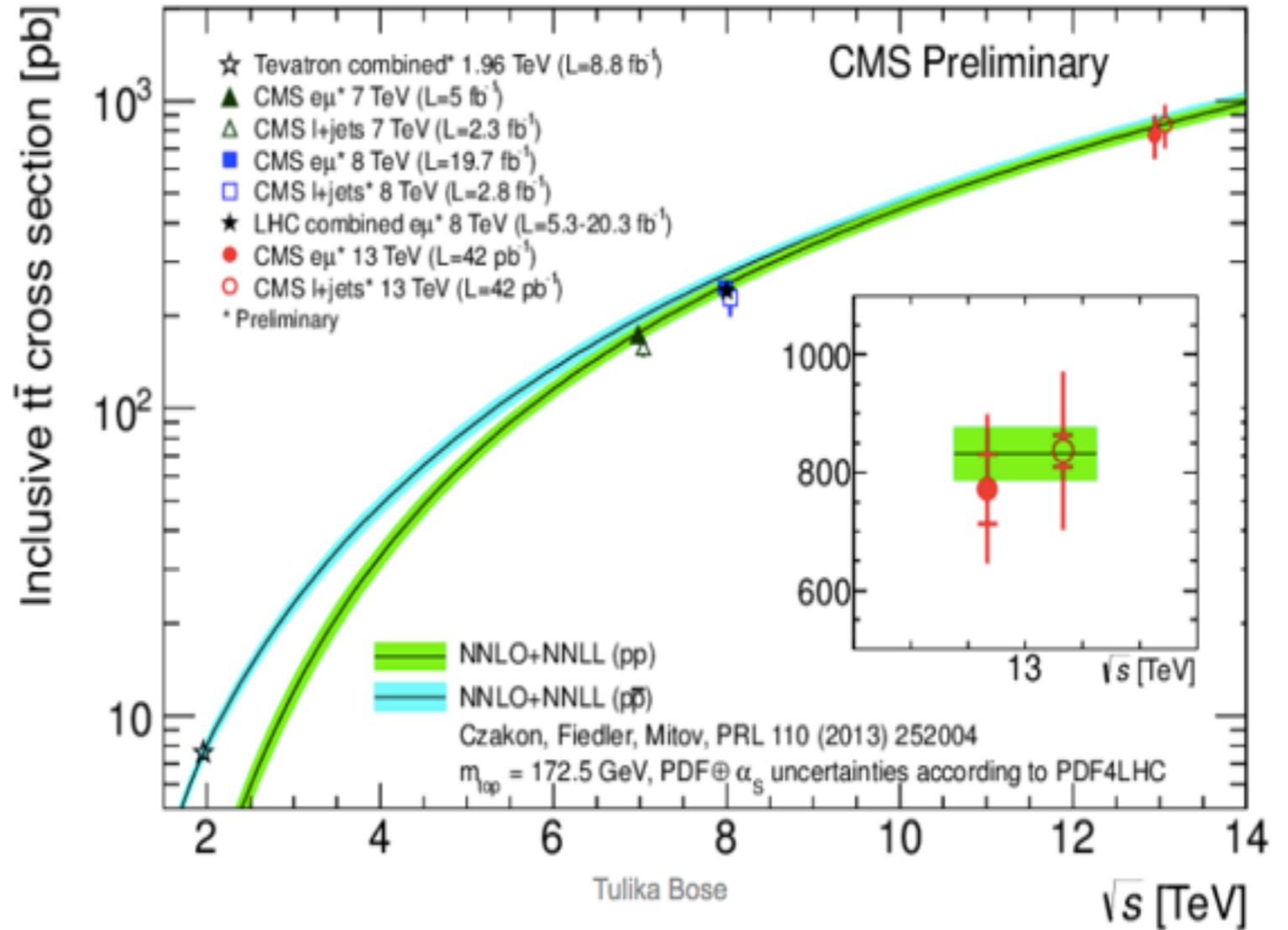
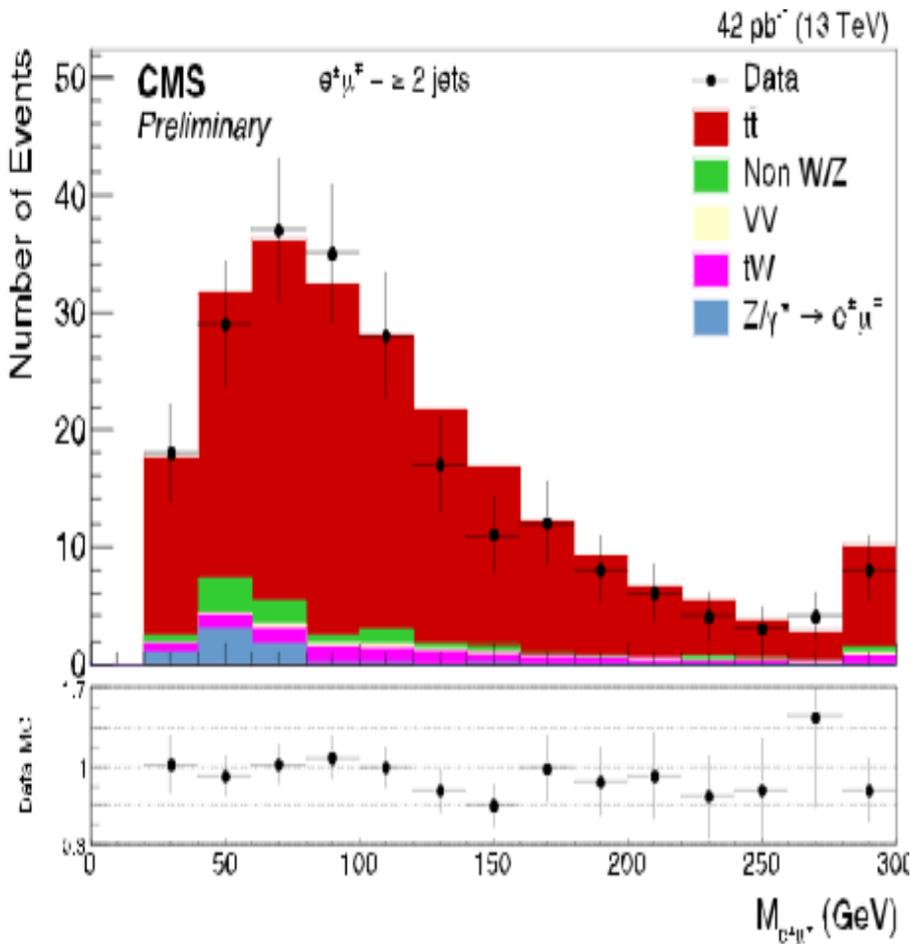
# t-tbar cross section, 13 TeV, CMS



Inclusive t-tbar cross section @13 TeV measured:

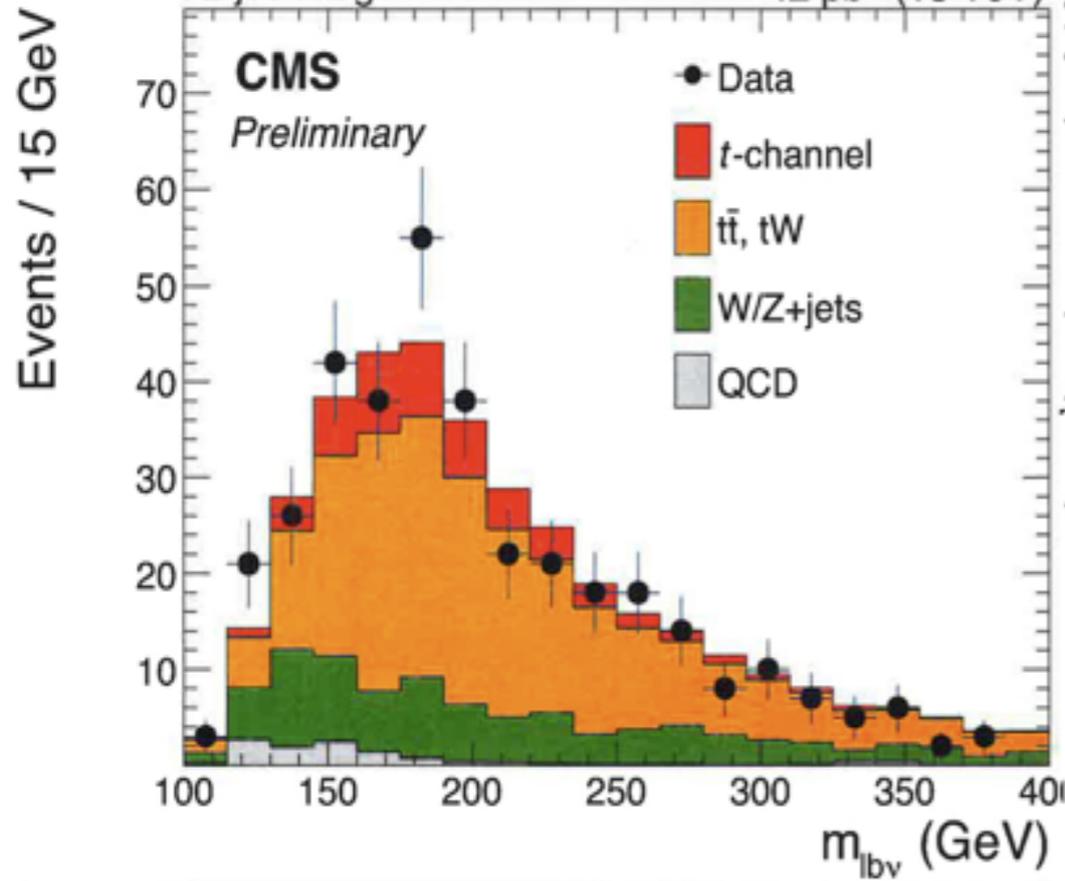
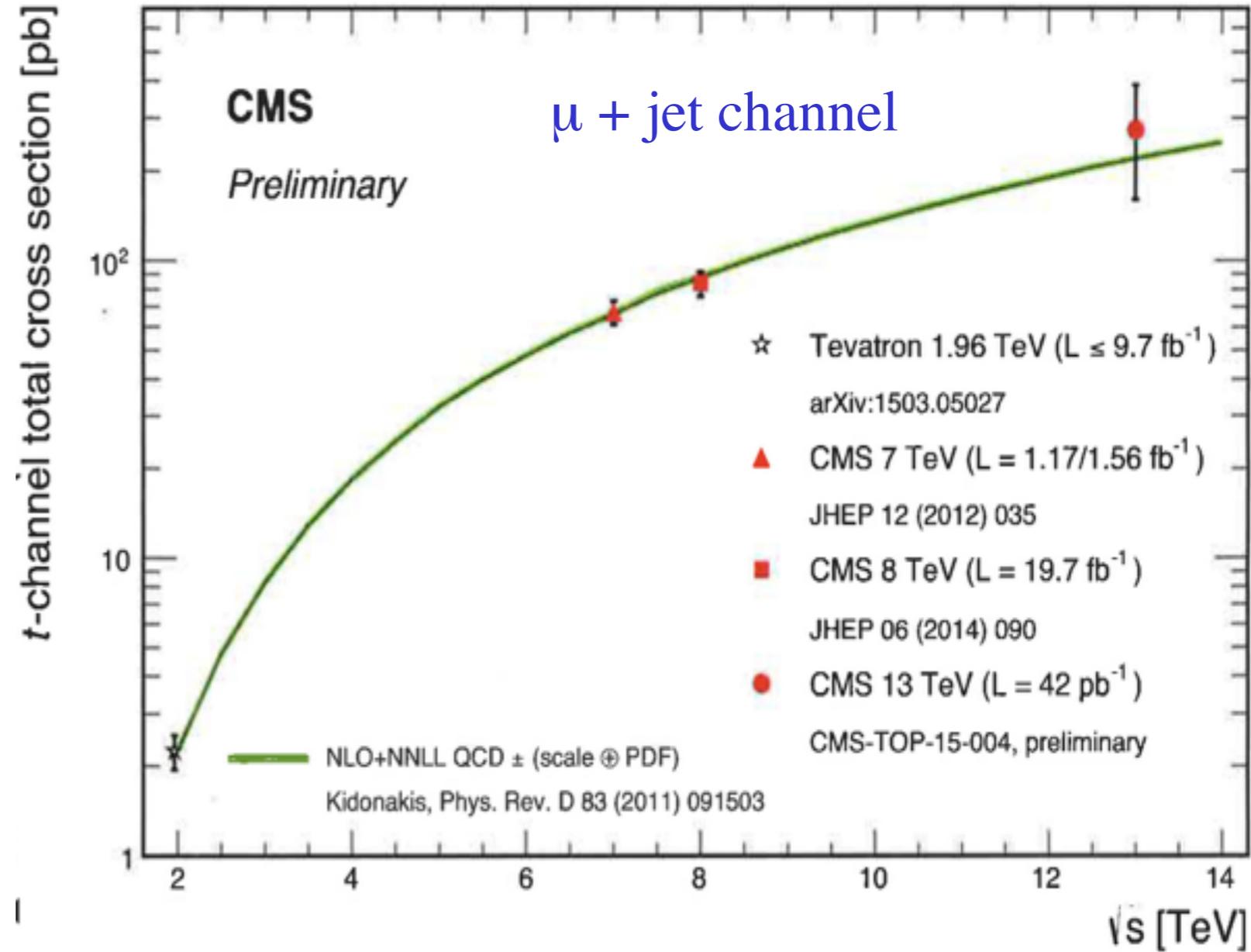
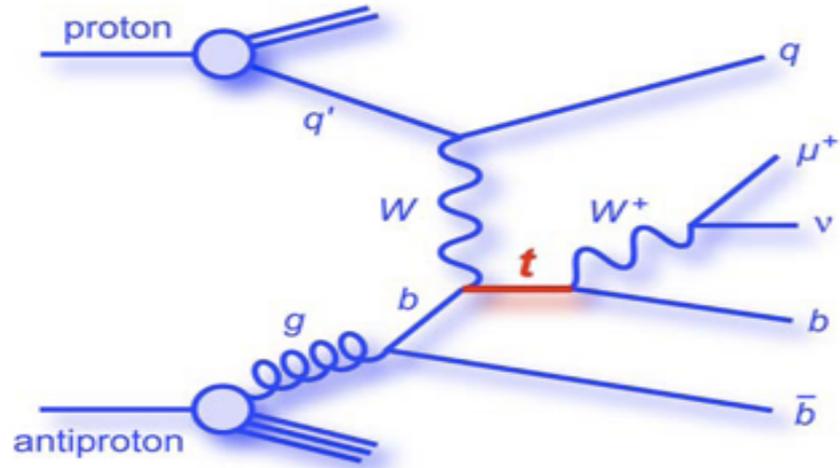
- $e\mu$  and semi-leptonic channels

TOP-15-005  
TOP-15-003



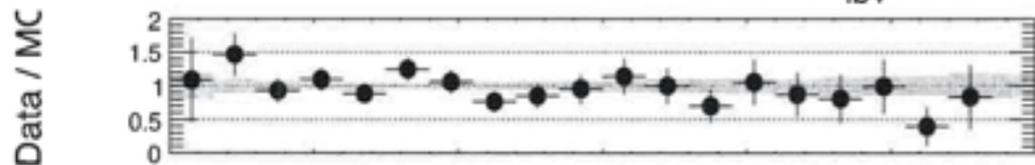


# Single top (t-channel) at 13 TeV - cross-section



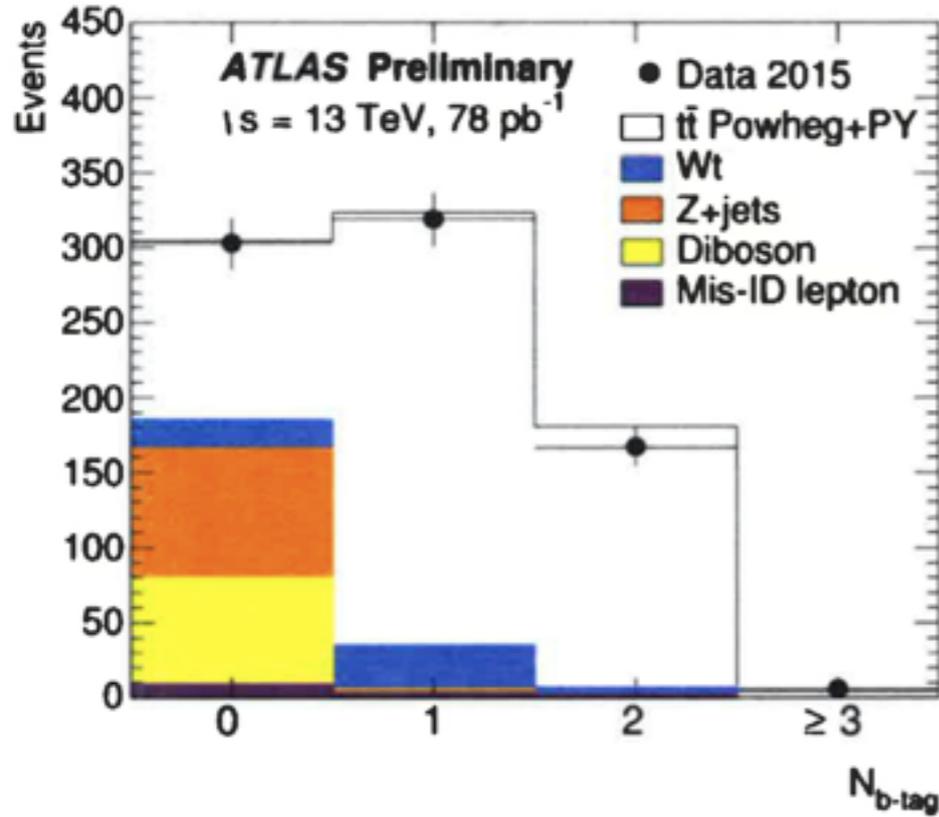
$$\sigma_{t\text{-cha}} = 274 \pm 98 \text{ (stat.)} \pm 52 \text{ (syst.)} \pm 33 \text{ (lumi.) pb}$$

$$|V_{tb}| = 1.12 \pm 0.24 \text{ (exp.)} \pm 0.02 \text{ (theor.)}$$

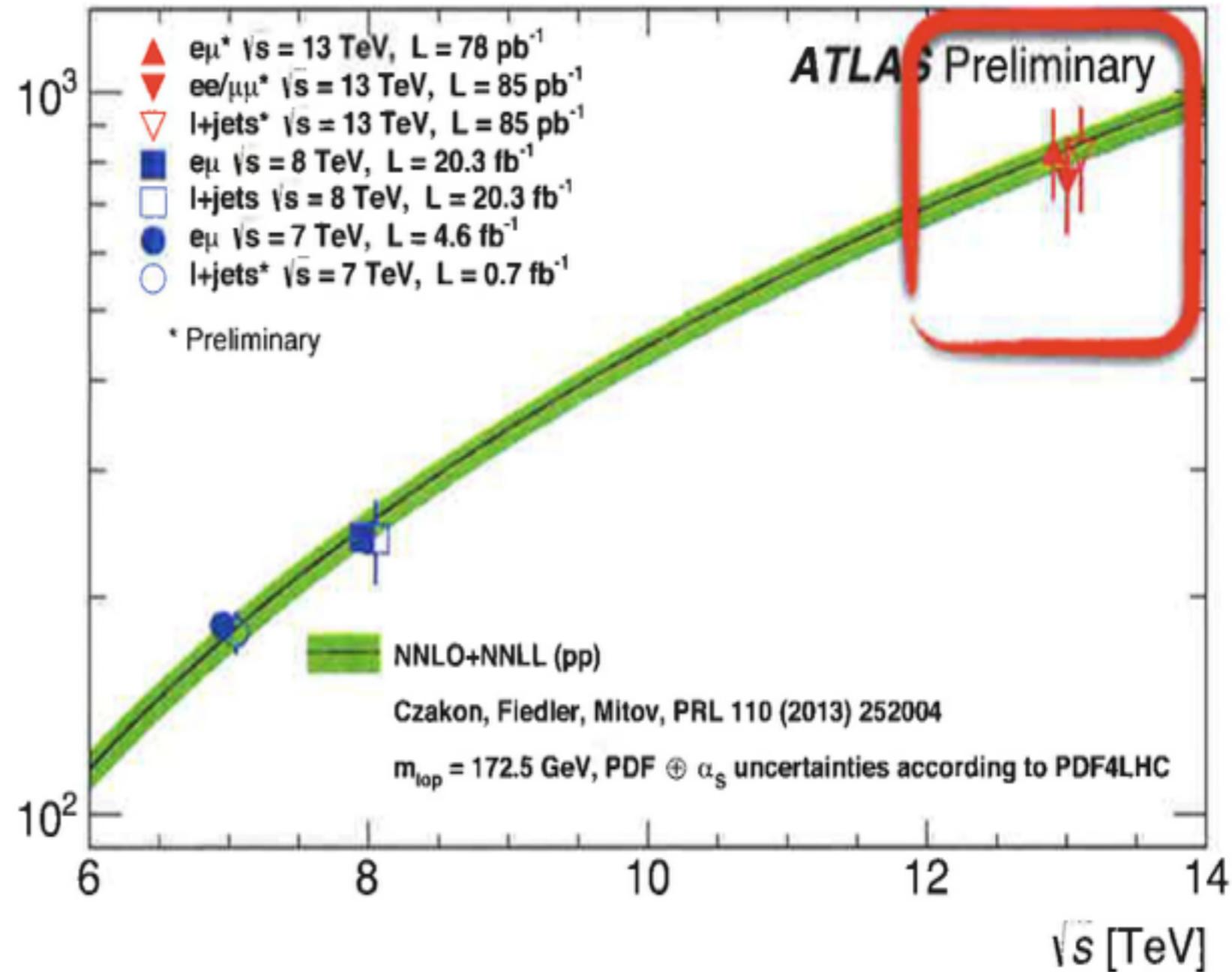




# t-tbar cross section, 13 TeV, ATLAS



Inclusive  $t\bar{t}$  cross section [pb]



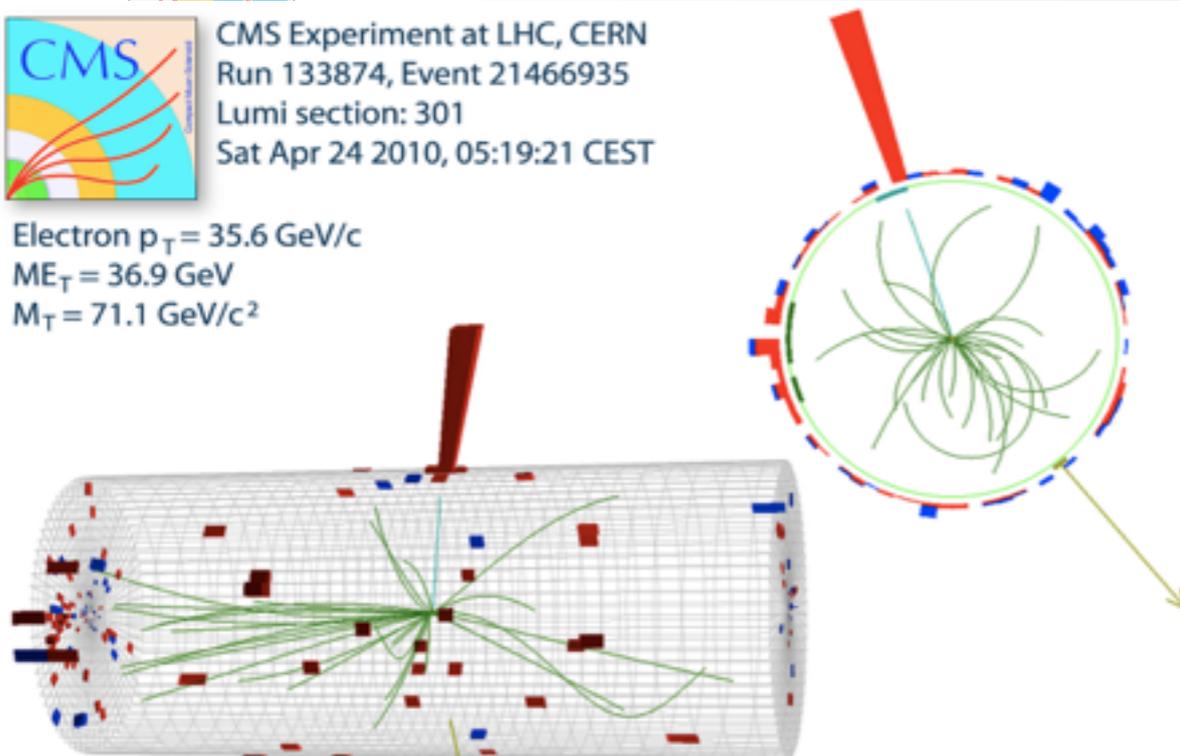


# LHC: First $W \rightarrow e\nu$ and $Z \rightarrow e^+e^-$ events, April 2010



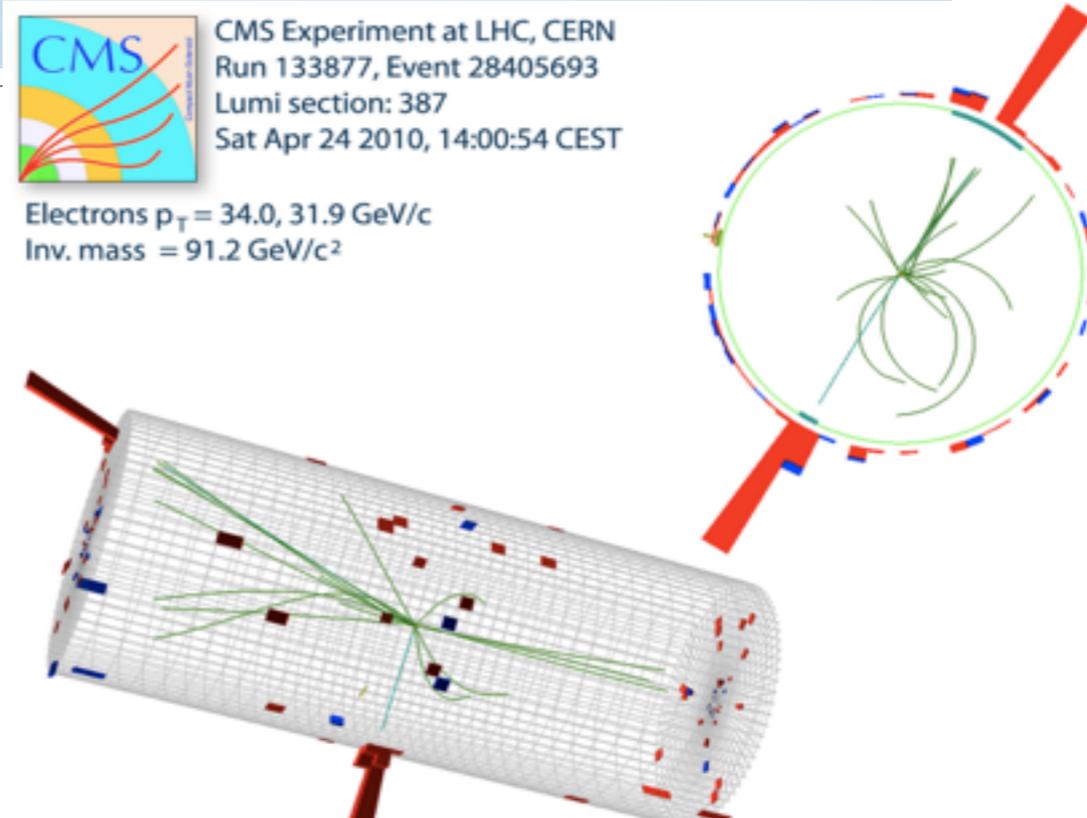
CMS Experiment at LHC, CERN  
Run 133874, Event 21466935  
Lumi section: 301  
Sat Apr 24 2010, 05:19:21 CEST

Electron  $p_T = 35.6$  GeV/c  
 $ME_T = 36.9$  GeV  
 $M_T = 71.1$  GeV/c<sup>2</sup>

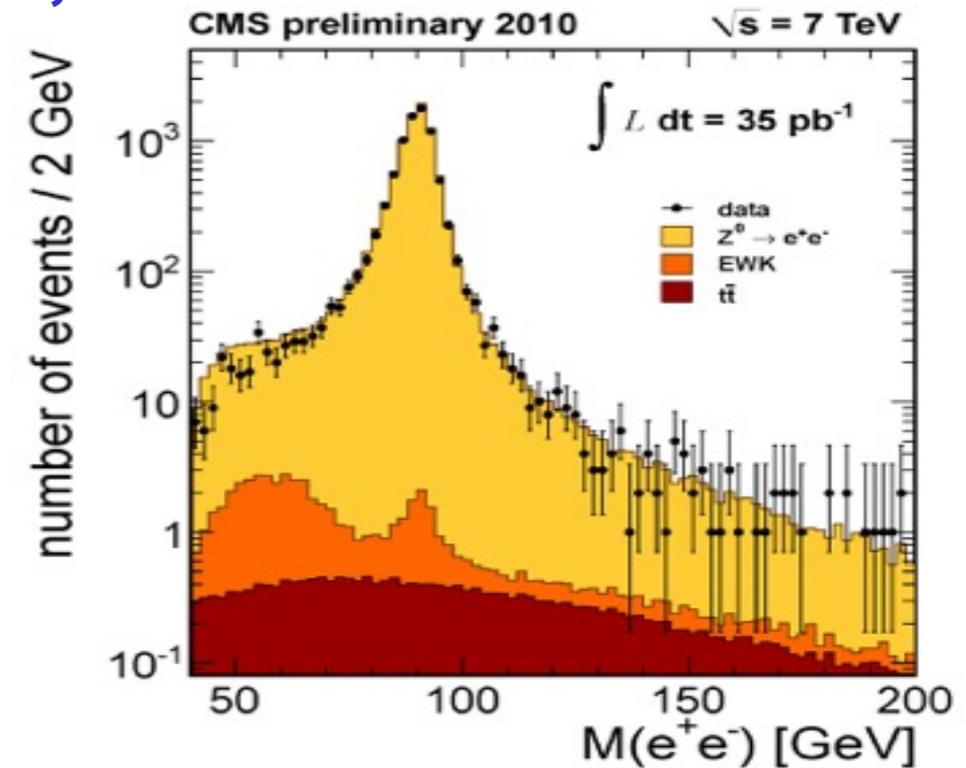
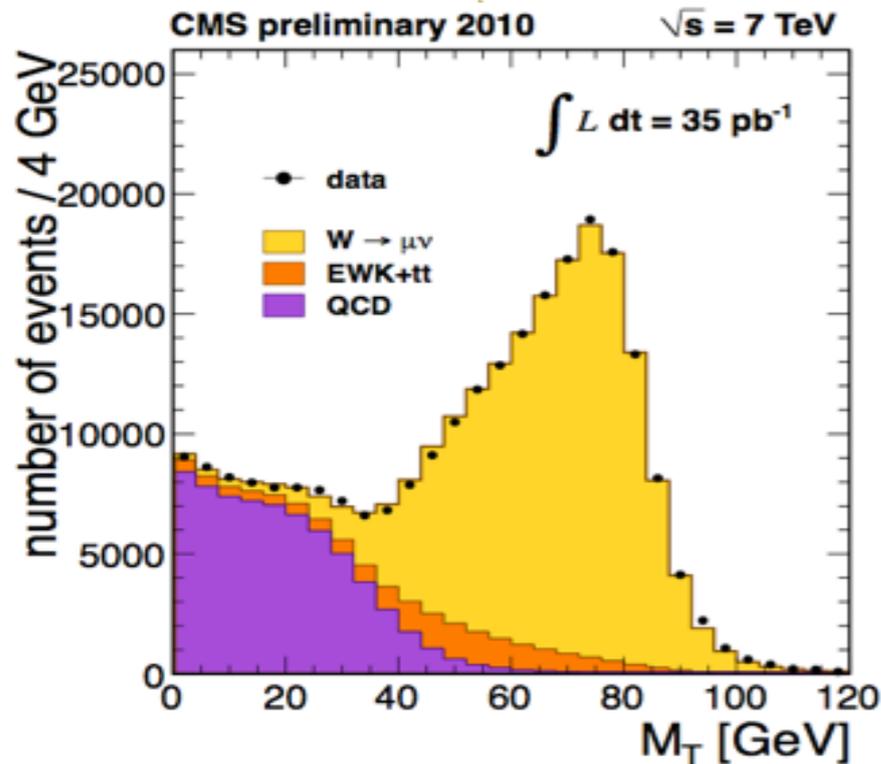


CMS Experiment at LHC, CERN  
Run 133877, Event 28405693  
Lumi section: 387  
Sat Apr 24 2010, 14:00:54 CEST

Electrons  $p_T = 34.0, 31.9$  GeV/c  
Inv. mass = 91.2 GeV/c<sup>2</sup>



## W and Z spectra in CMS, Nov. 2010



By end-2012 we had  
~150.000.000 W and  
~15.000.000 Z  
decaying leptonically!!

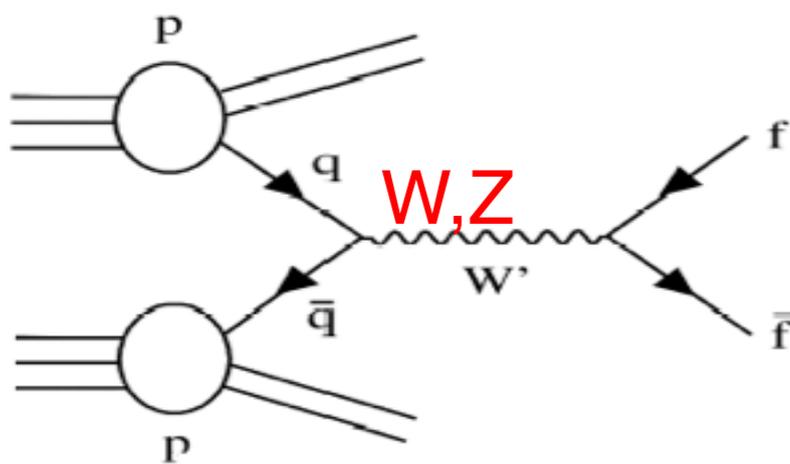


# W, Z production cross sections, testing QCD

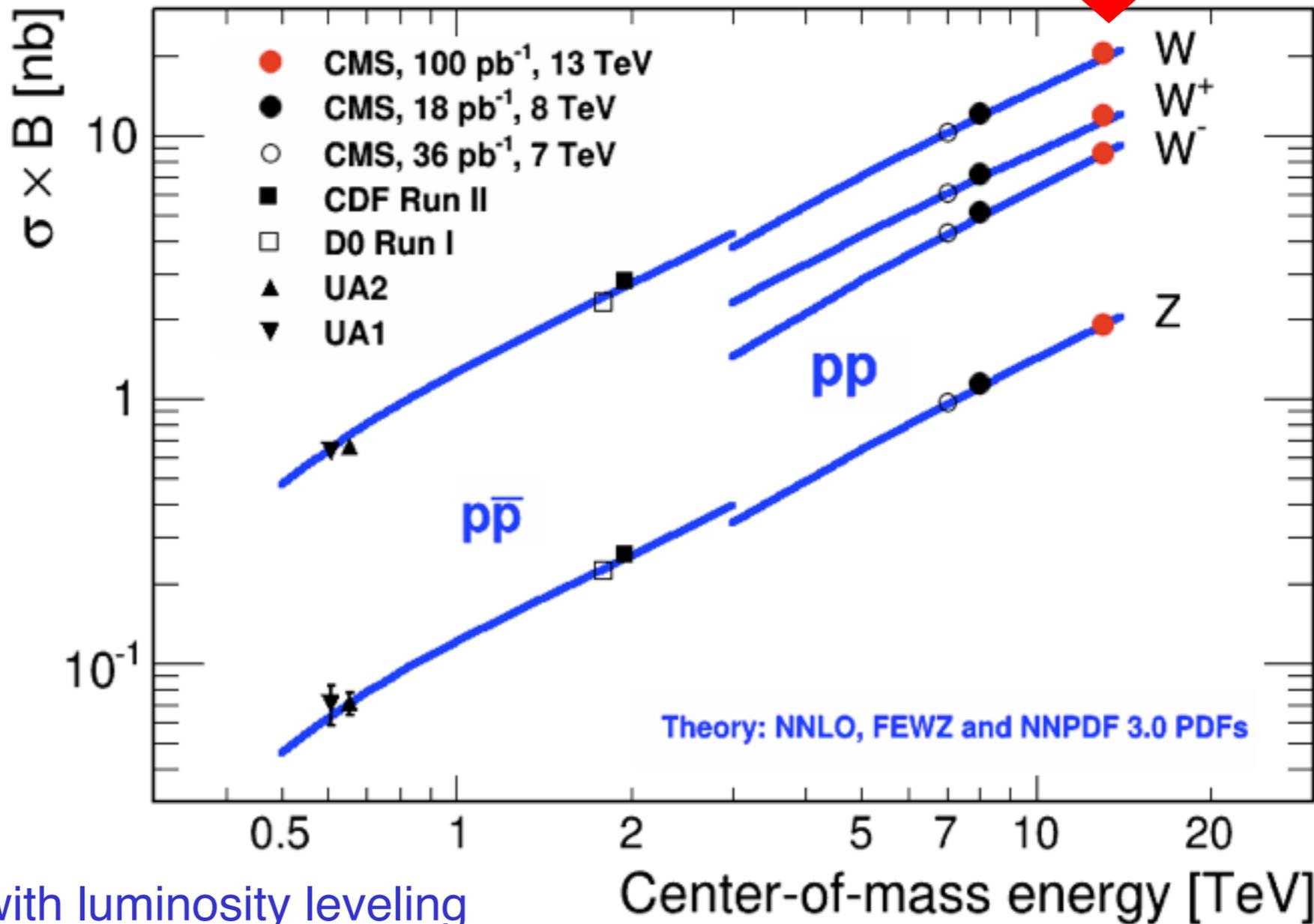
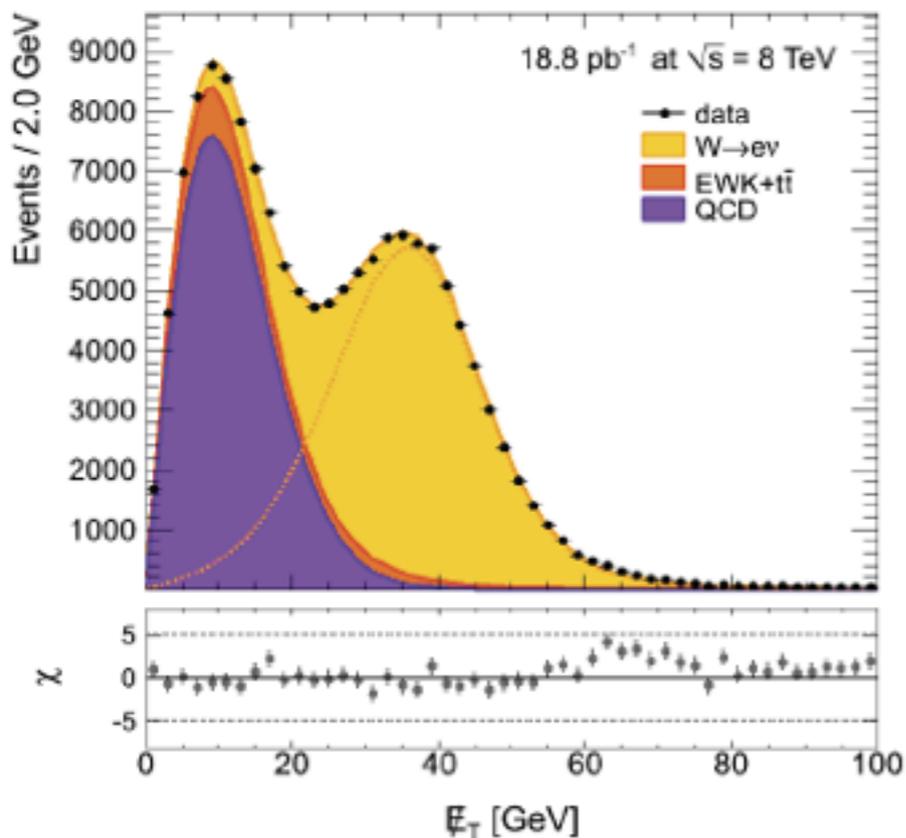
from the CERN pp-bar collider to the Tevatron and the LHC

W, Z at 13 TeV, CMS, first look June 3rd

Production and Decay of a W'



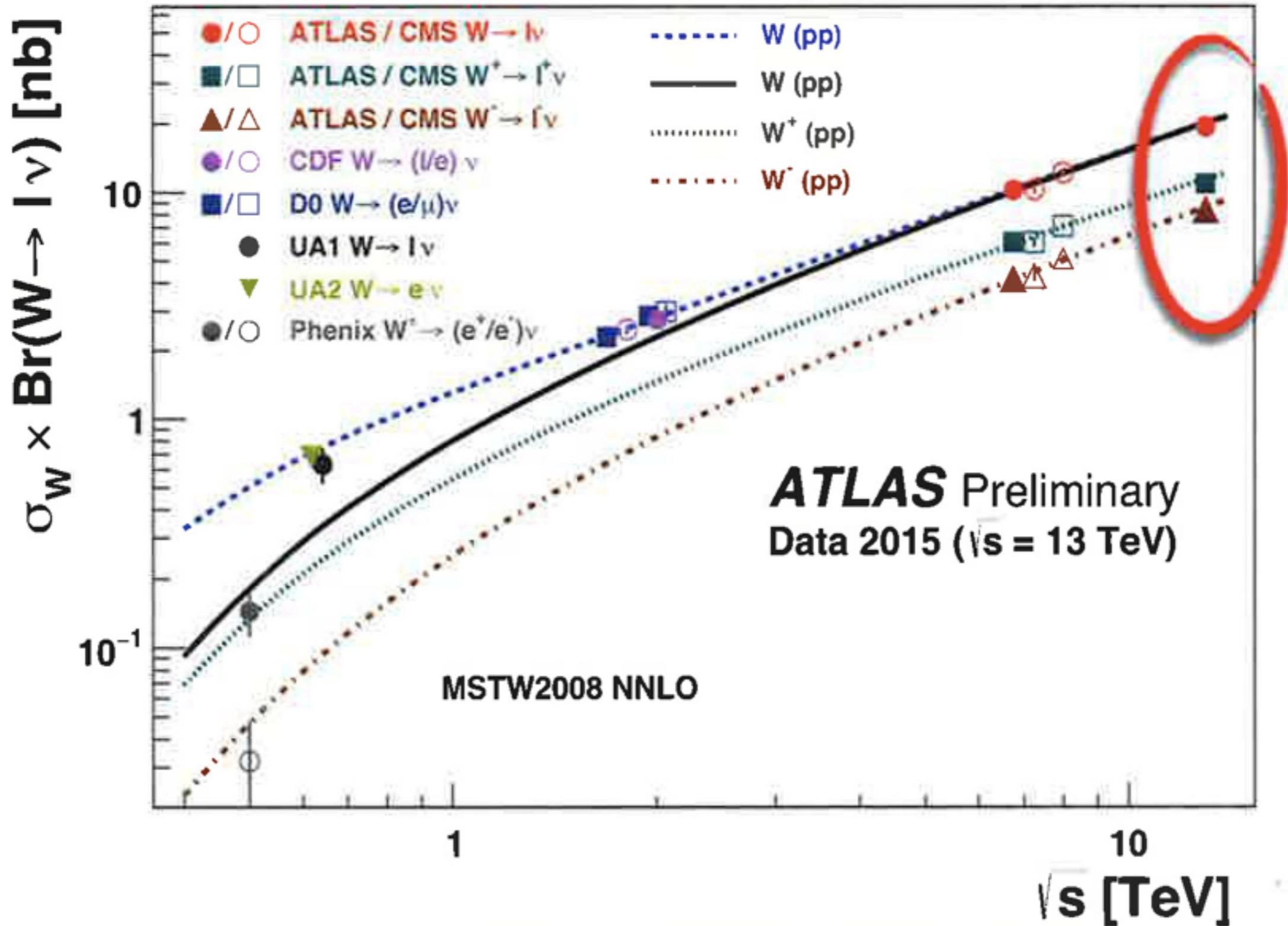
CMS Preliminary



Use special low-pile-up runs with luminosity leveling

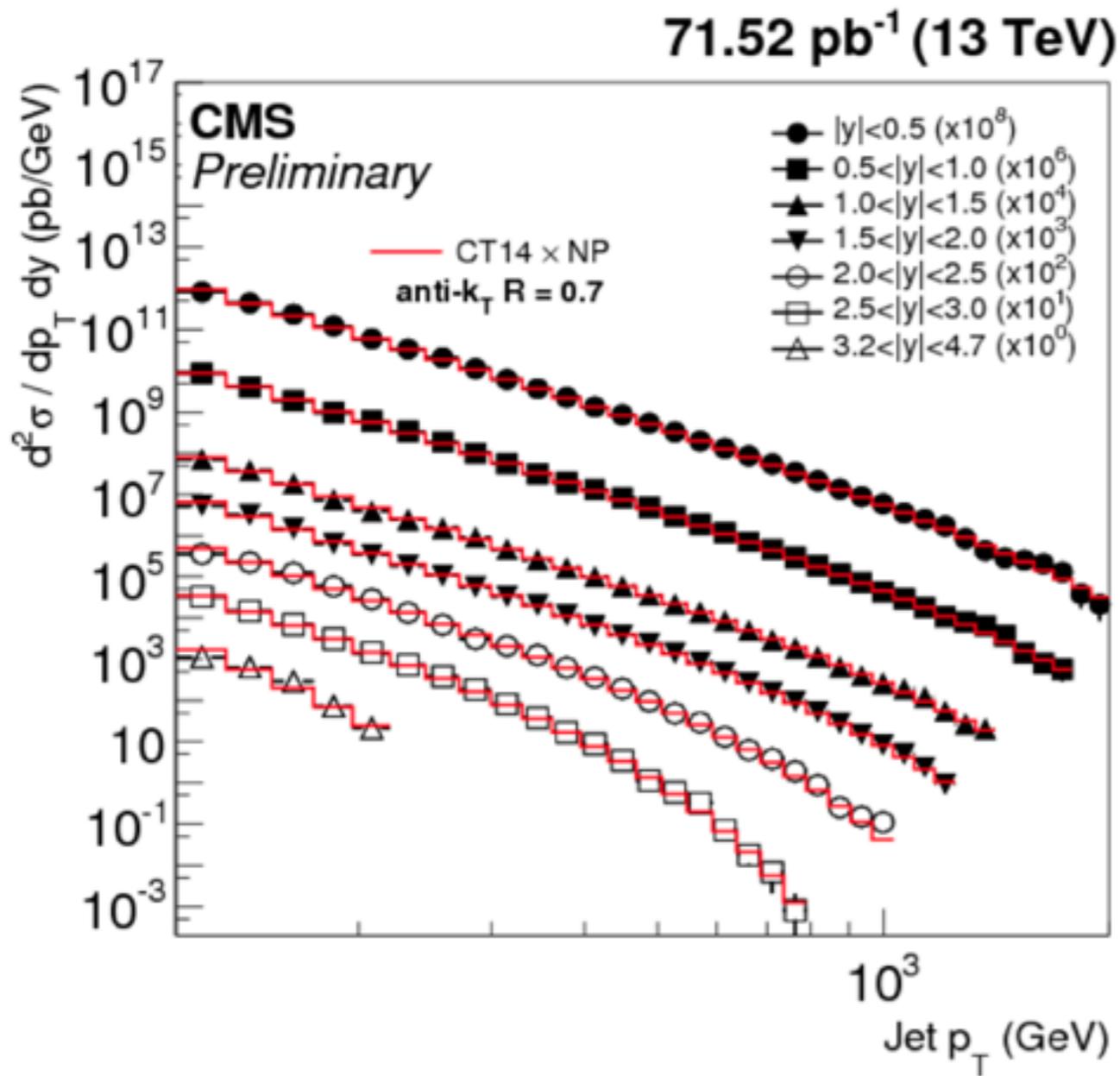


# W cross sections at 13 TeV, ATLAS

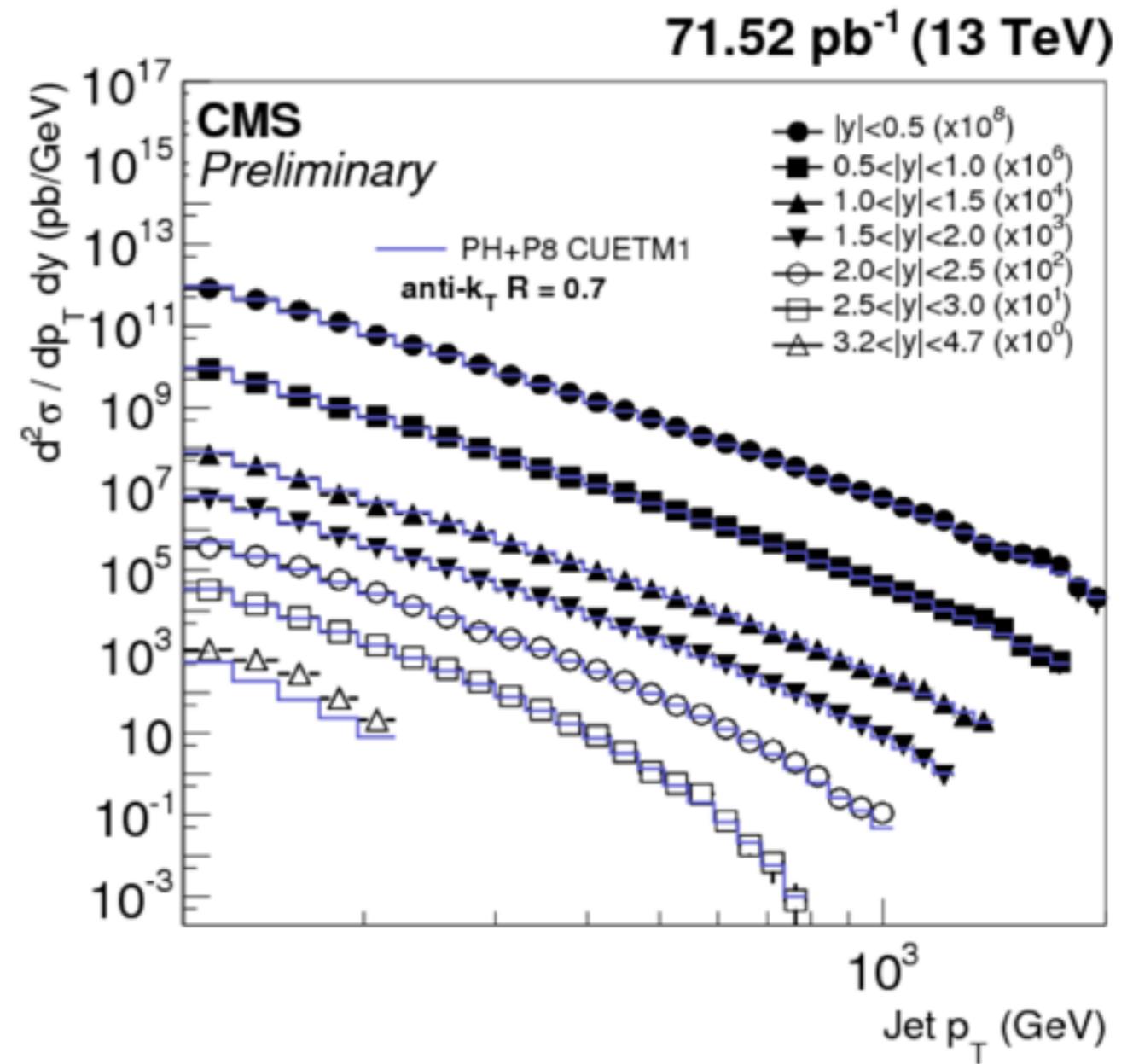




# First look at 13 TeV for JETS



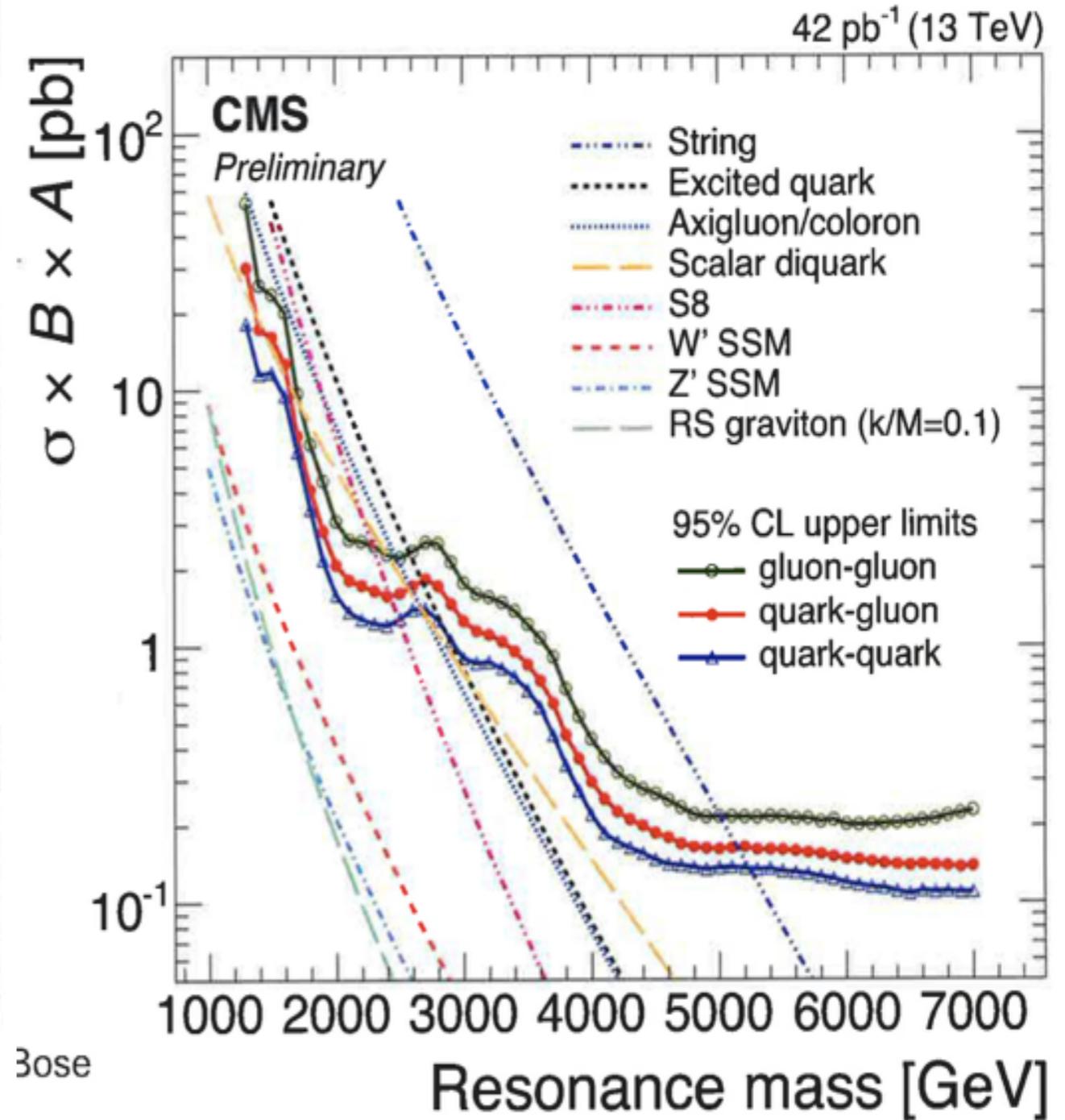
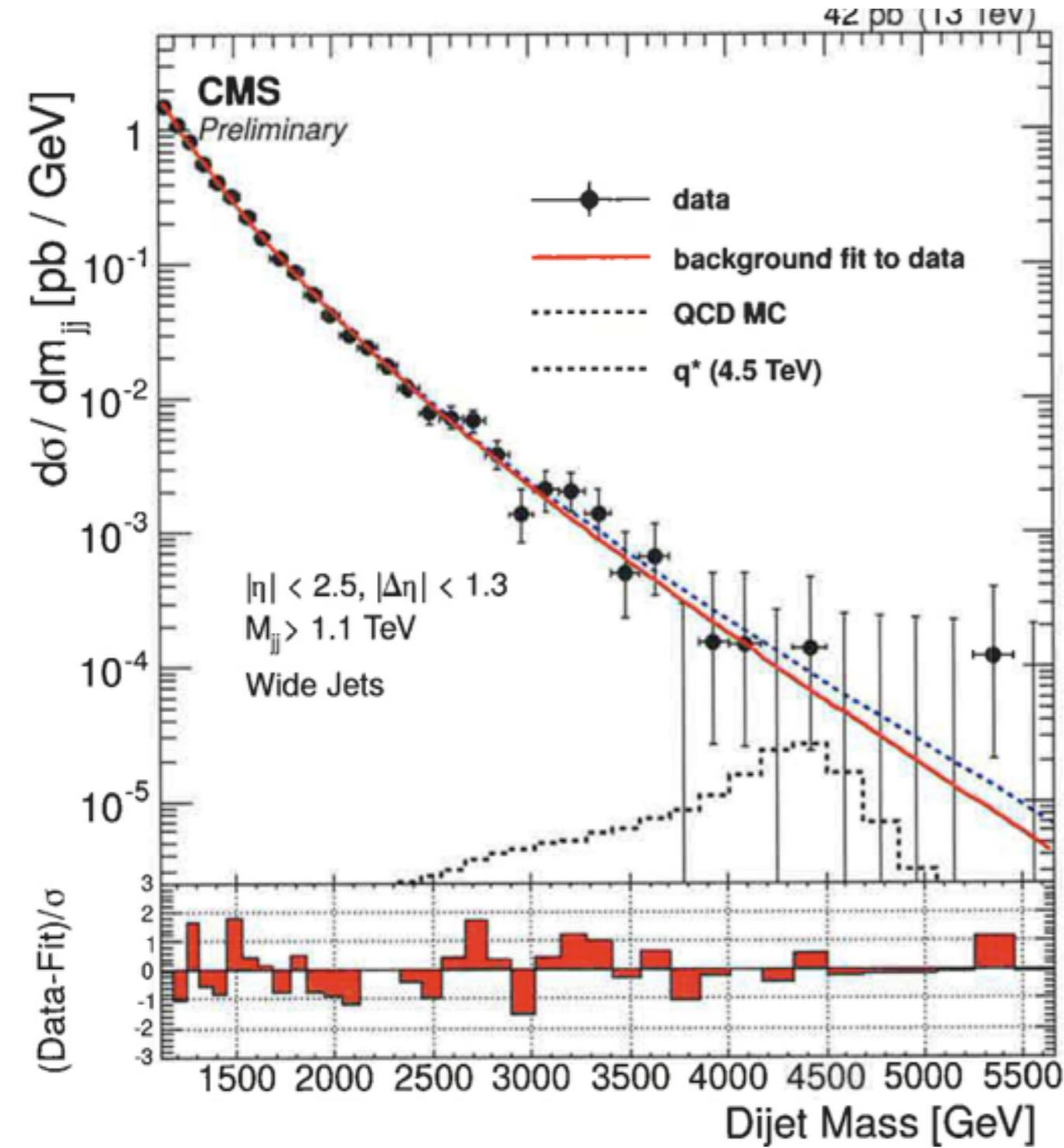
NLOJet++



Powheg+Py8 (CUETM1)

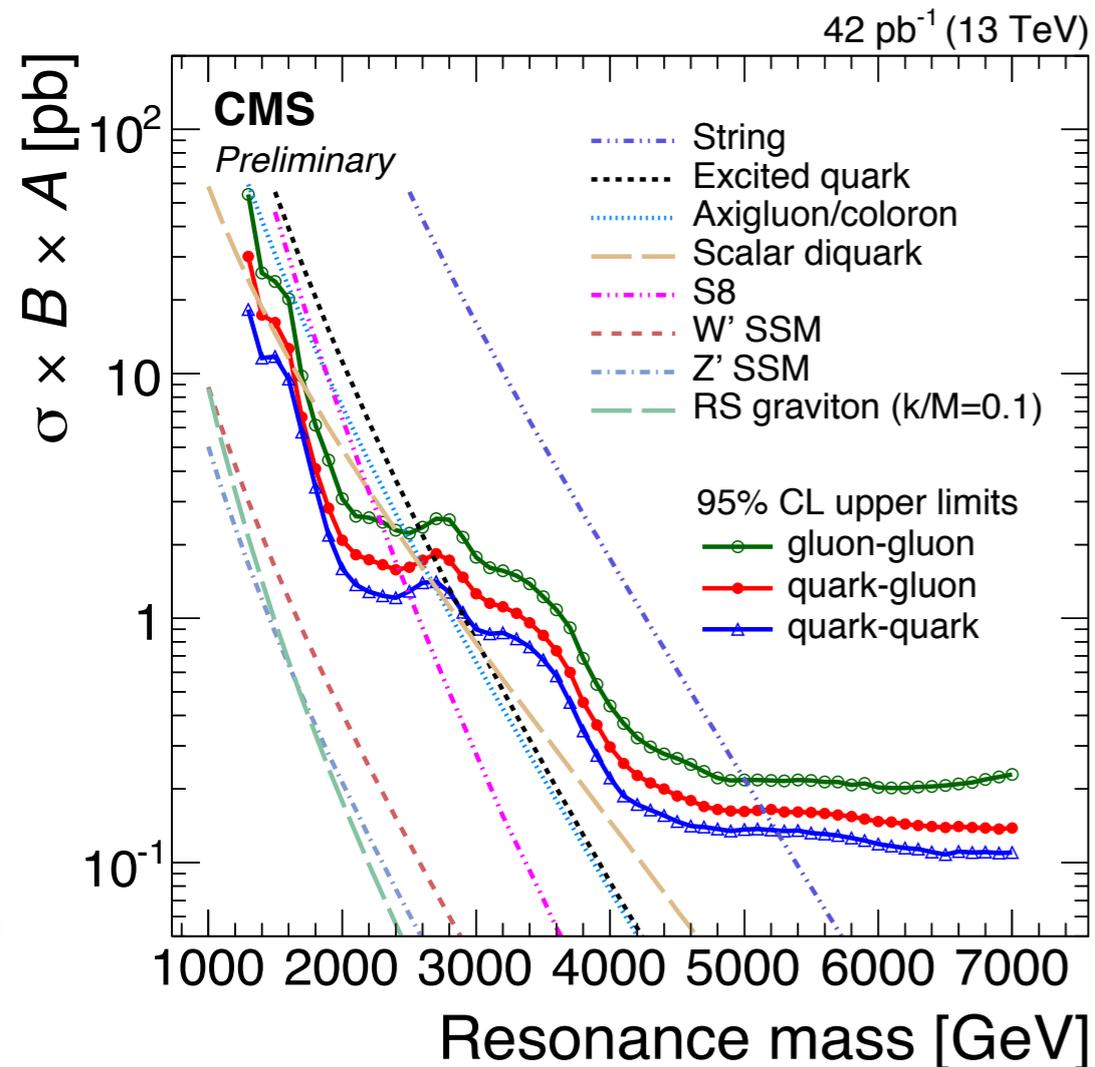


Inclusive di-jets at 13 TeV, 2015 data, CMS -1  
- already excluding heavy resonances with 42 pb



# Di-jet resonance search

CMS PAS EXO-15-001



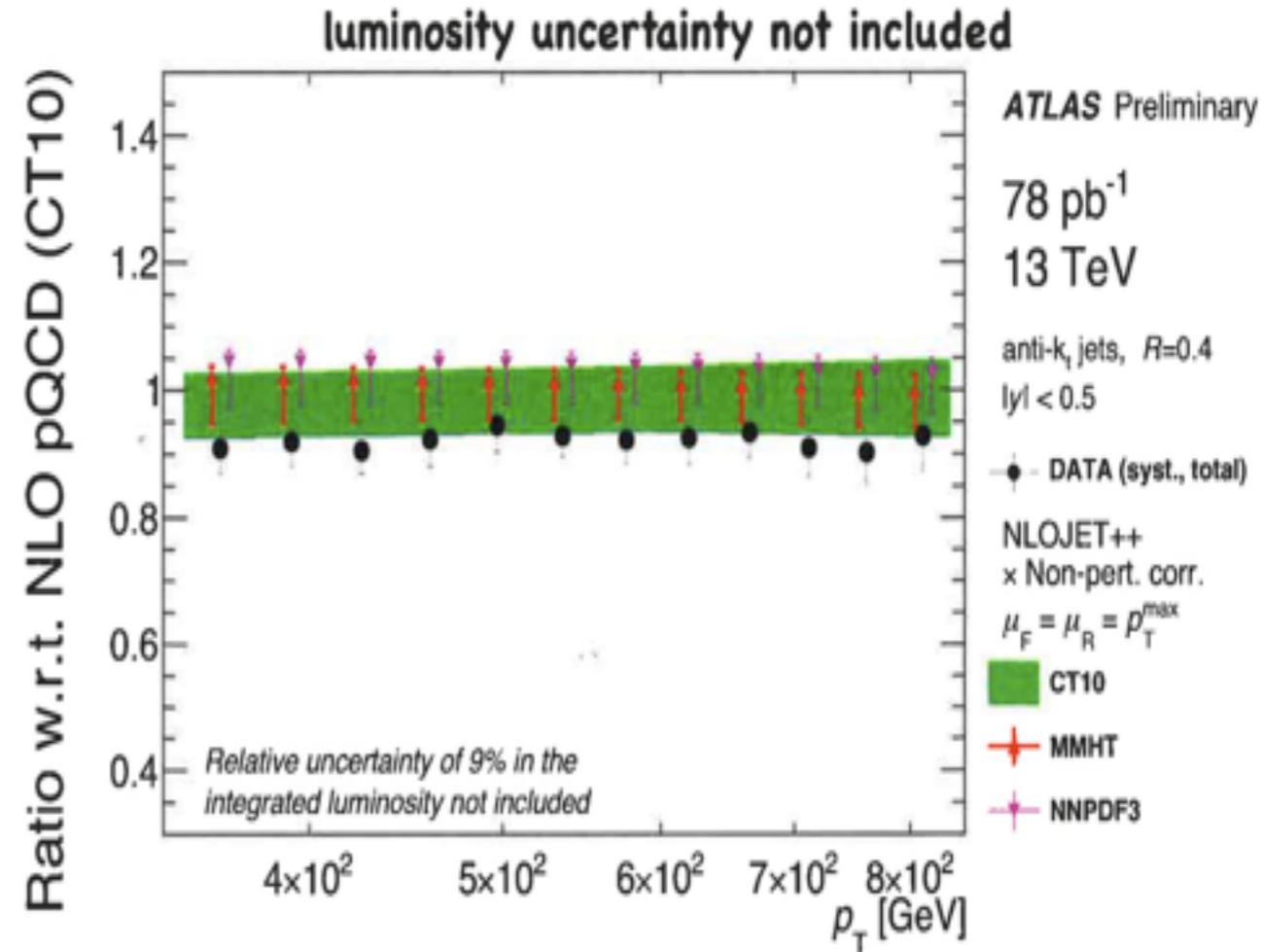
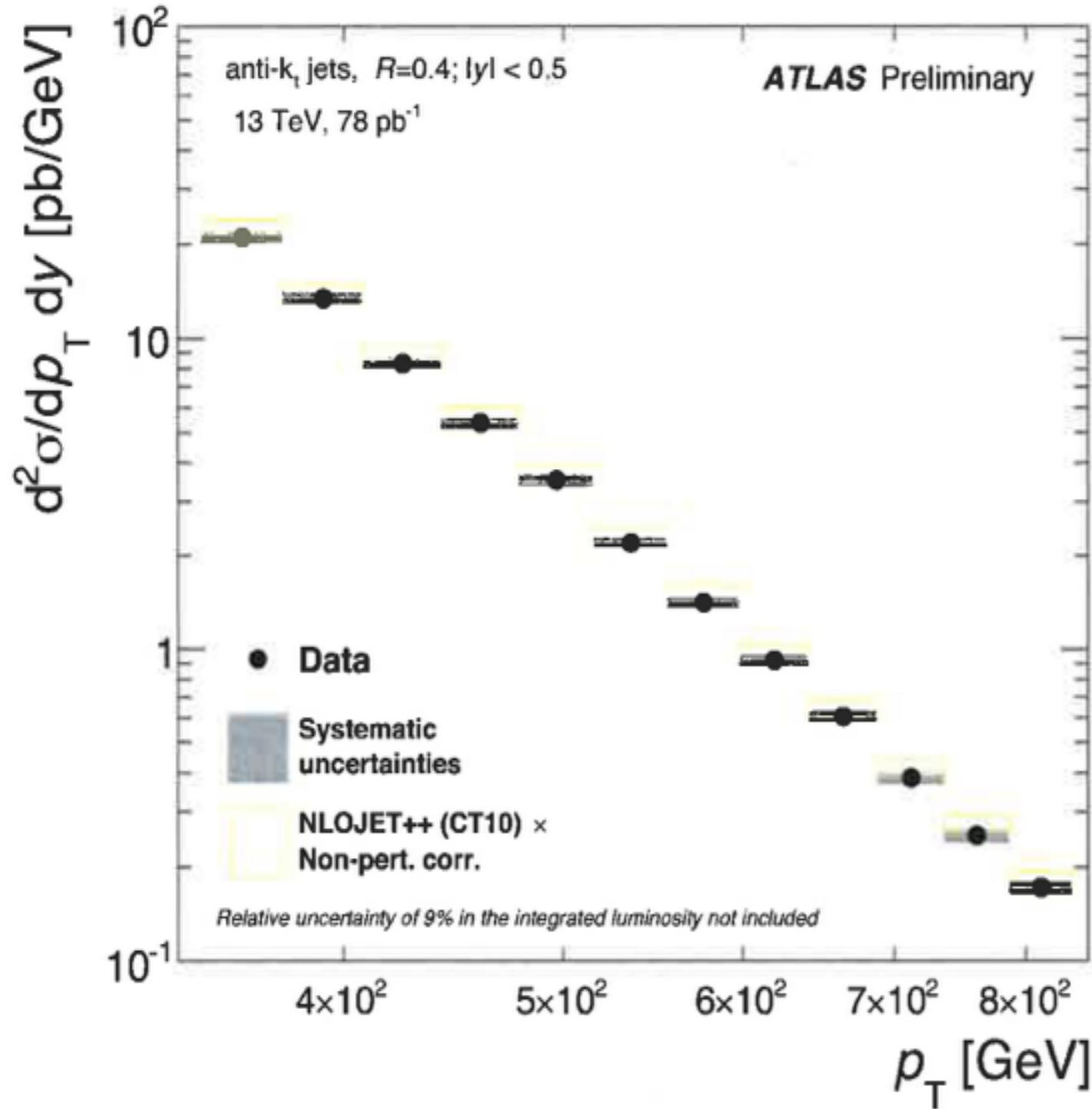
Confirms Run2 is already more sensitive than Run1 for  $M > 5$  TeV

- Observed limits at 95% CL on cross section of  $qq, qg, gg$  resonances
- Get worse when there are gluons in the final state because radiation increases and resolution degrades
- Extend to 7 TeV in di-jet mass for the first time
- plateaus at high mass due to absence of events

Model	Mass Limits (TeV)			
	Run 1 (20 fb <sup>-1</sup> )		Run 2 (42 pb <sup>-1</sup> )	
	Observed	Expected	Observed	Expected
<b>String Resonance (S)</b>	<b>5.0</b>	<b>4.9</b>	<b>5.1</b>	<b>5.2</b>
Excited Quark (q*)	3.5	3.7	2.7	2.9
Axigluon (A) / Coloron (C)	3.7	3.9	2.7	2.9
Scalar Diquark (D)	4.7	4.7	2.7	3.3
Color Octet Scalar (S8)	2.7	2.6	2.3	2.0



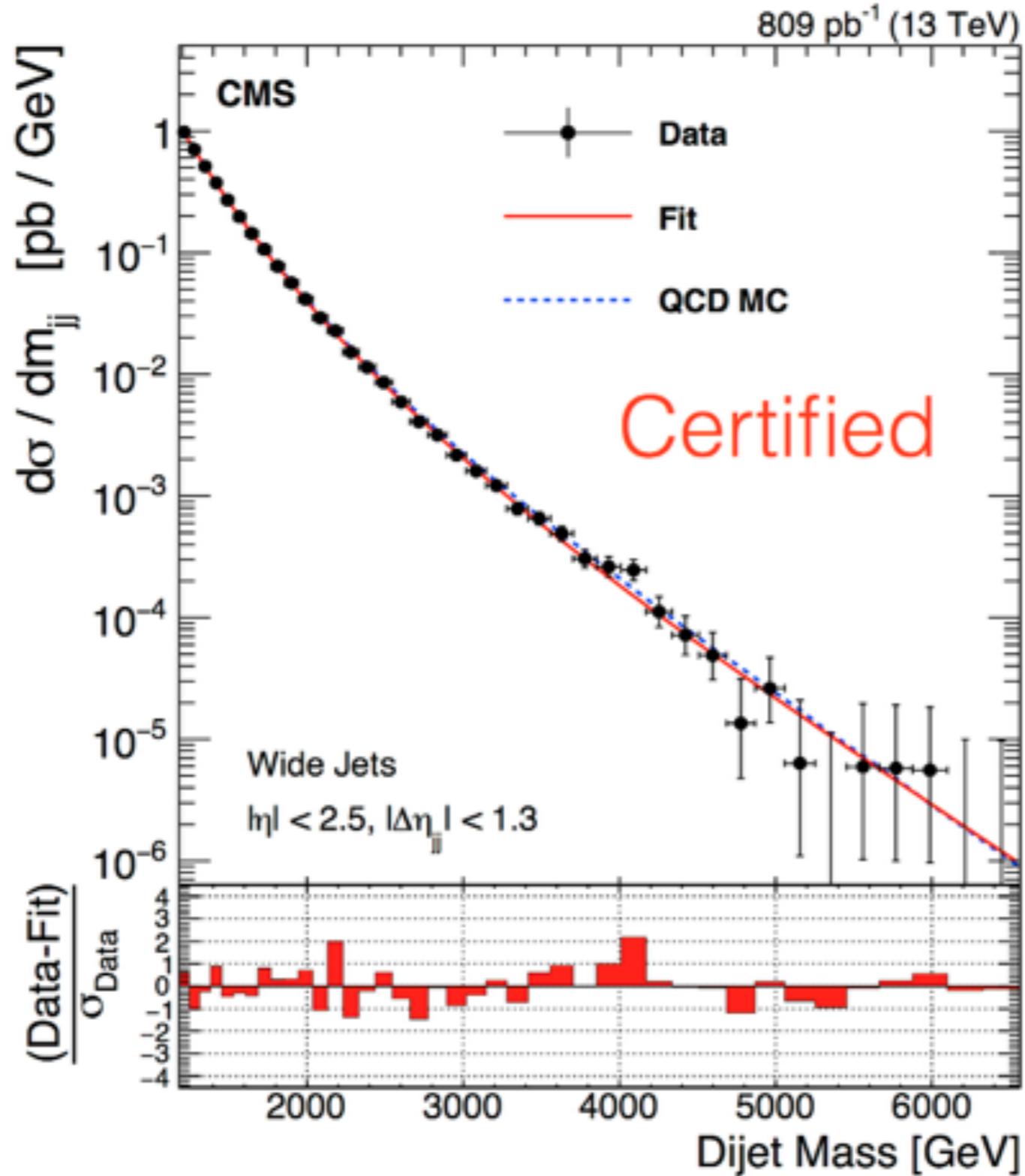
# Inclusive jets at 13 TeV, 2015 data, ATLAS



good agreement with pQCD calculation

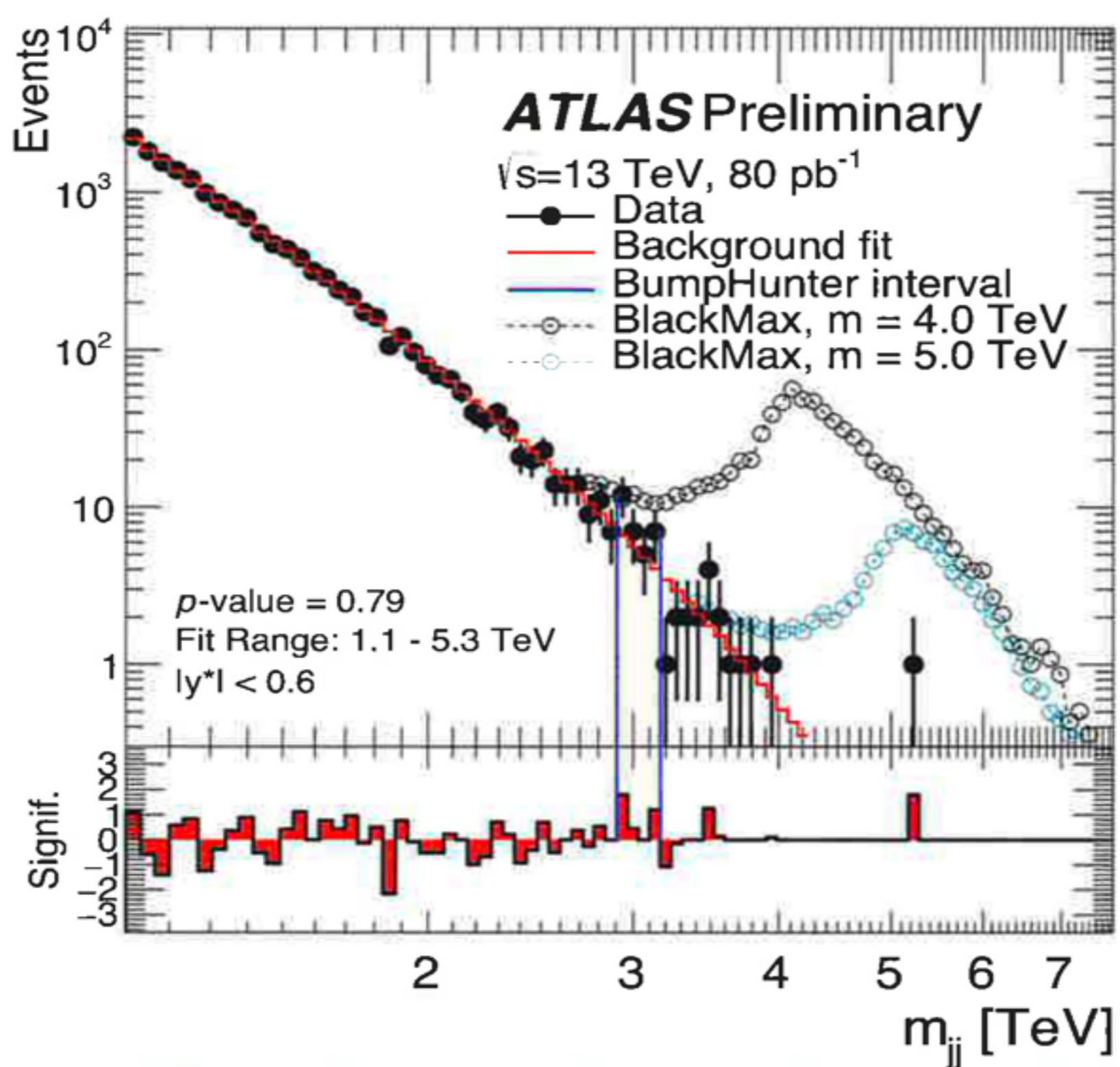


# Dijets – effective mass





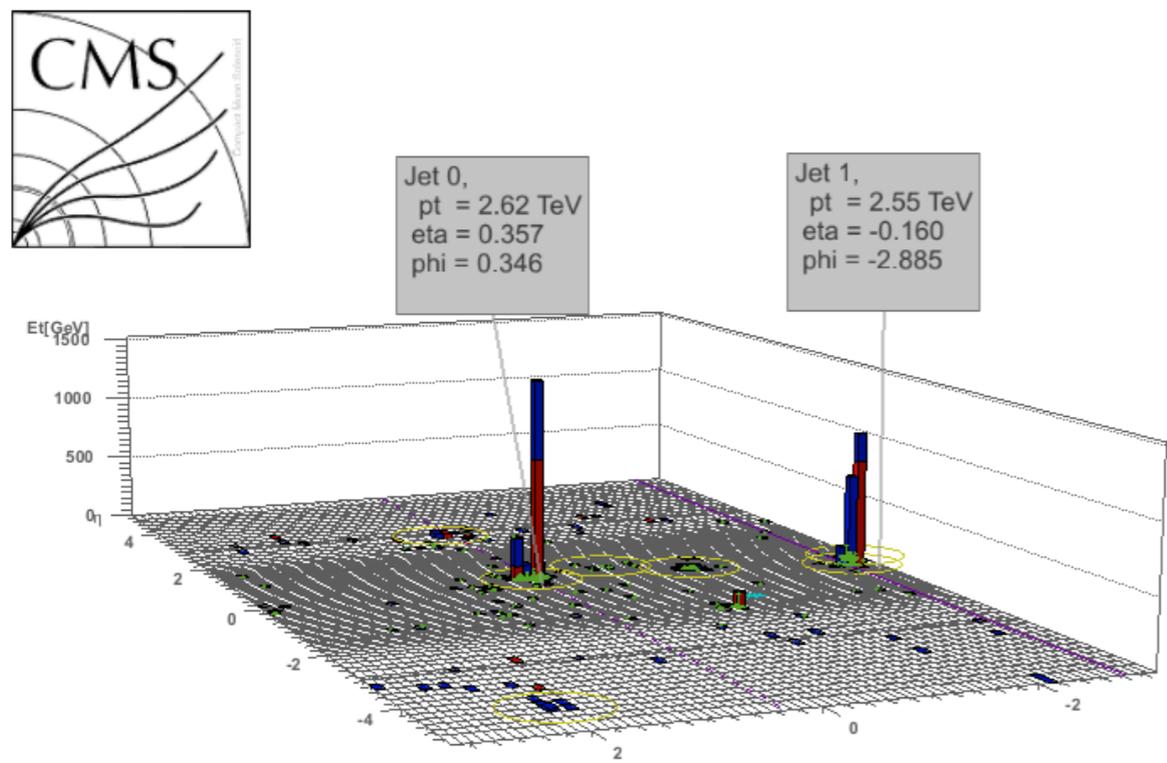
Dijet masses, ATLAS, 13 TeV,  
Black Holes exclusion



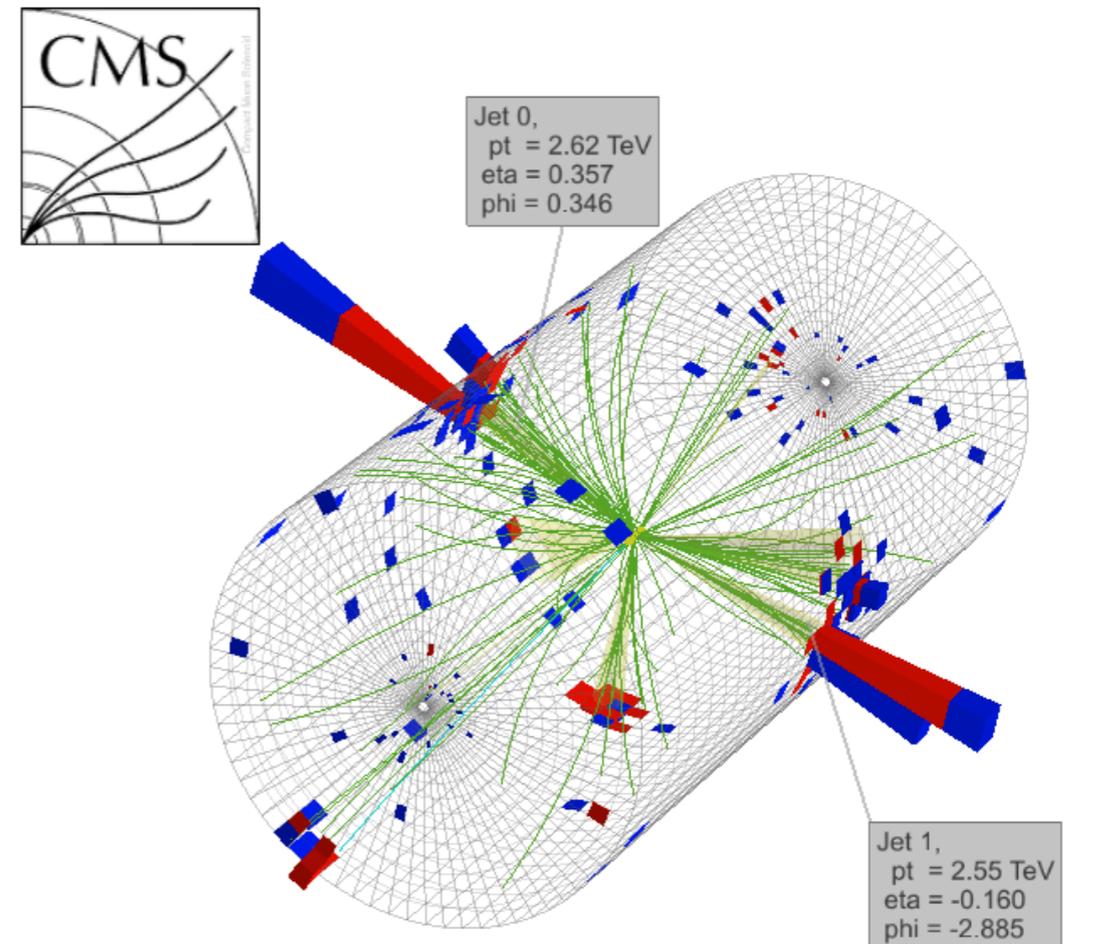
# Di-jet resonance search

CMS PAS EXO-15-001

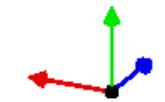
*Highest Mass di-jet event  $M = 5.4$  TeV*



CMS Experiment at LHC, CERN  
Data recorded: Sun Jul 12 01:52:51 2015 CDT  
Run/Event: 251562 / 310157776  
Lumi section: 347  
Dijet Mass : 5.4 TeV



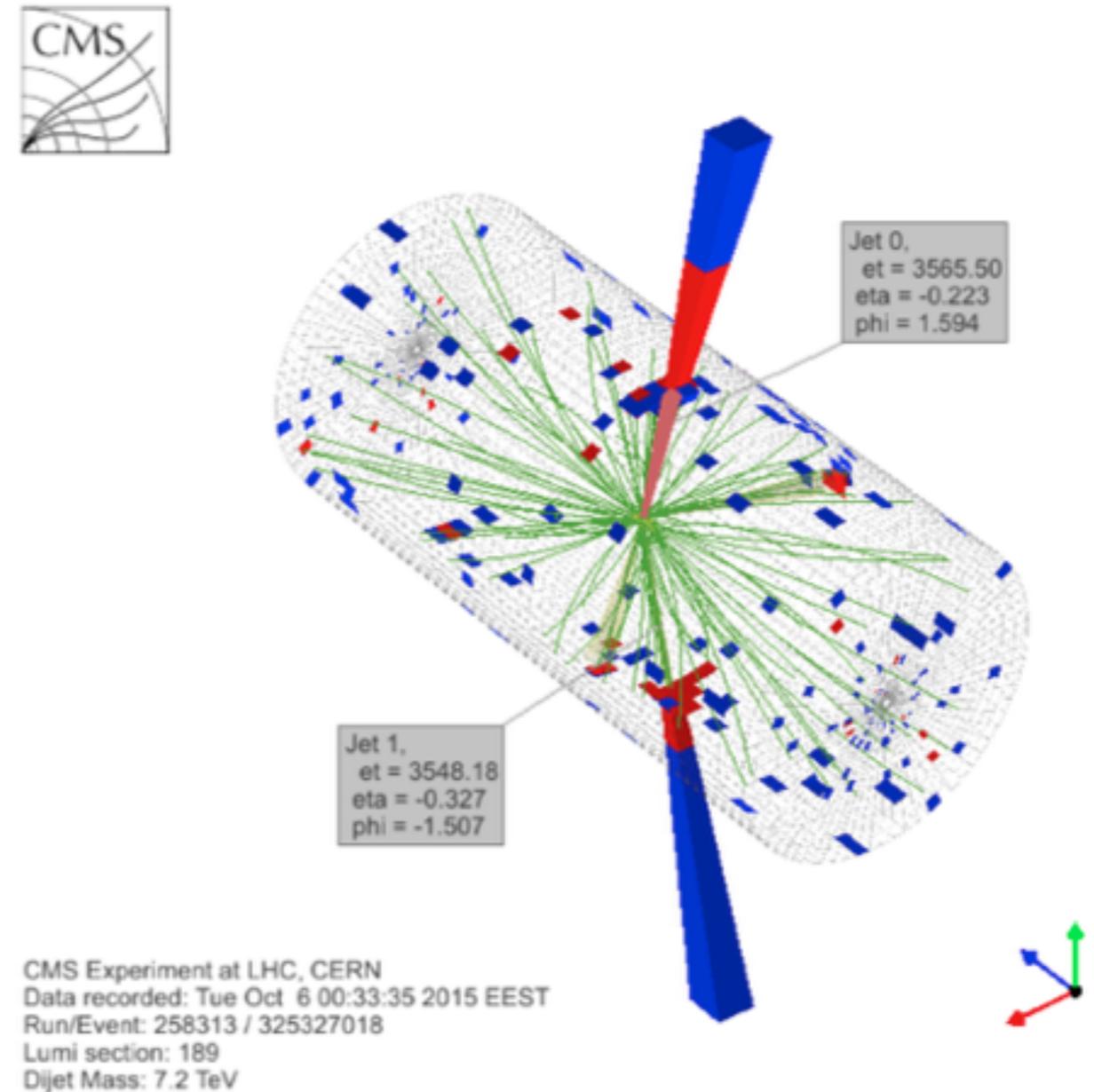
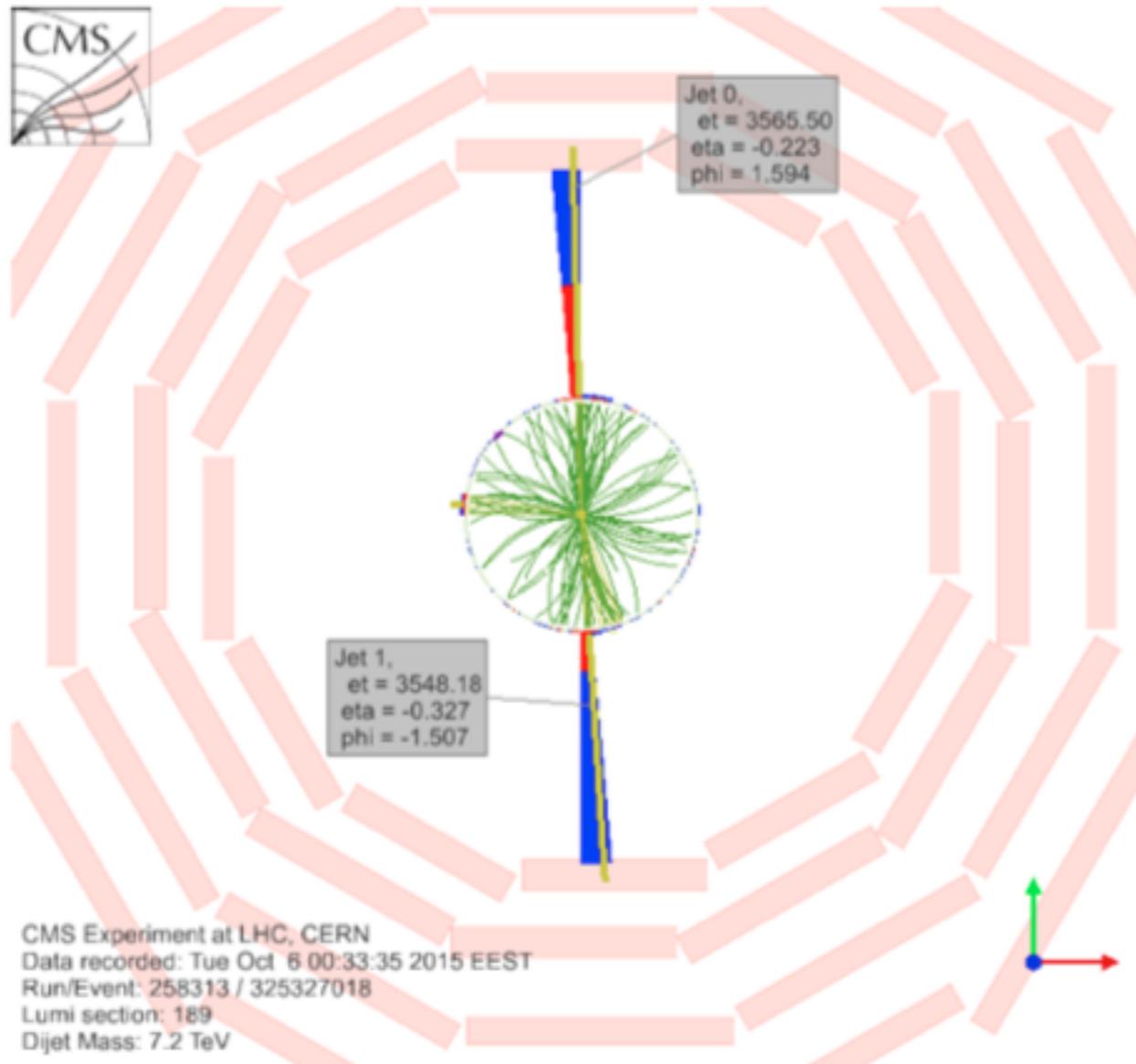
CMS Experiment at LHC, CERN  
Data recorded: Sun Jul 12 01:52:51 2015 CDT  
Run/Event: 251562 / 310157776  
Lumi section: 347  
Dijet Mass : 5.4 TeV



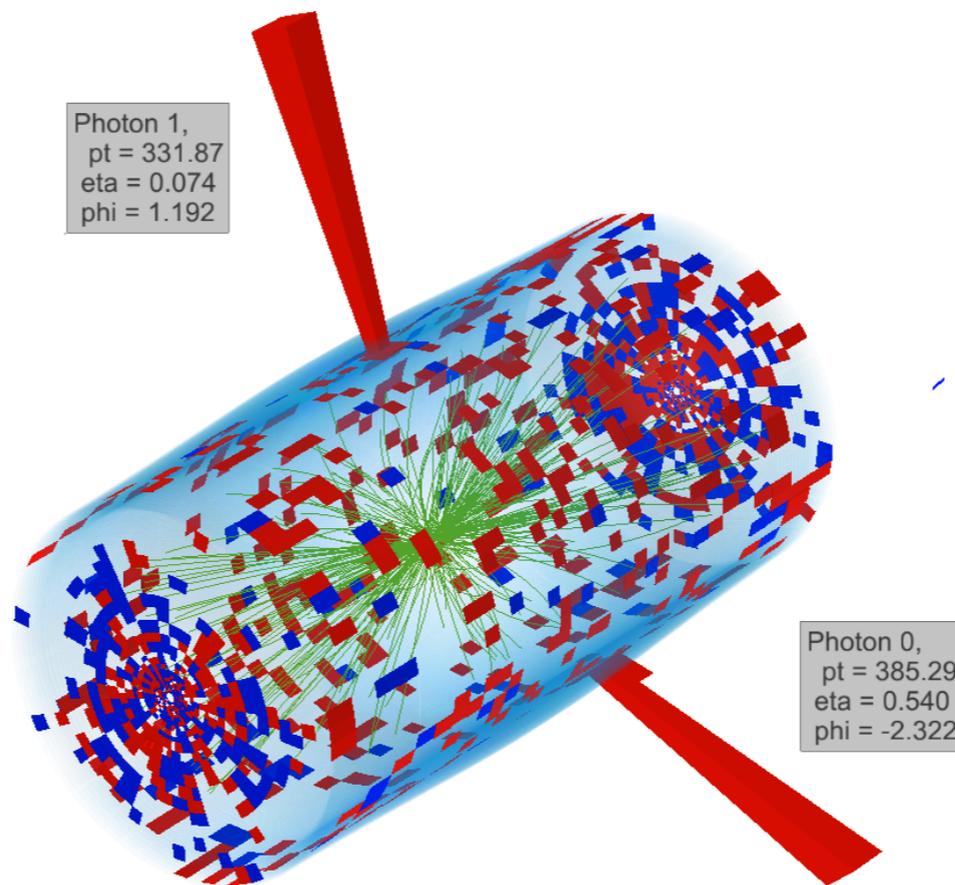
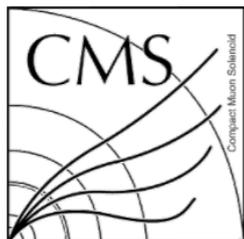


# Highest dijet mass event

- **Dijet mass = 7.2 TeV**
  - very-well balanced dijet event



# Event display of the highest mass di-photon candidate ( $M = 730$ GeV)



$m^{\gamma\gamma} = 730$  GeV  
 $p_T^{\gamma\gamma} = 50$  GeV  
 $E_T^{\text{miss}} = 20$  GeV  
 $N_{\text{vtx}} = 28$

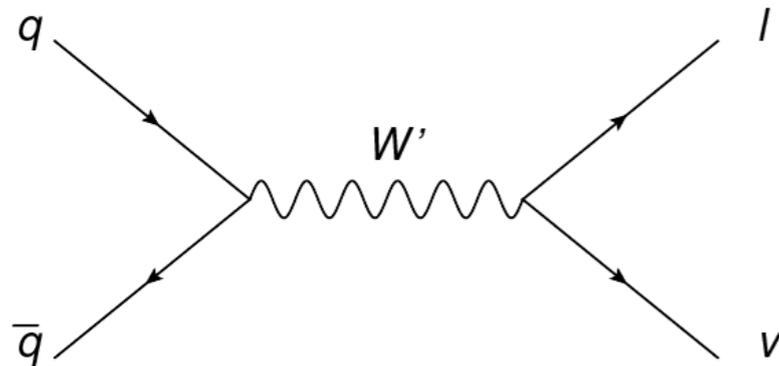
CMS Experiment at LHC, CERN  
Data recorded: Thu Jul 16 04:37:00 2015 CEST  
Run/Event: 251883 / 108749975  
Lumi section: 171  
Orbit/Crossing: 44591162 / 323



## Photon selection

$p_T > 100$  GeV and  $|\eta| < 2.5$  with at least one candidate in the ECAL Barrel with  $|\eta| < 1.4442$   
isolated photons with shape in ECAL compatible with prompt photon

# Muon + MET resonance Search



## Muon selection

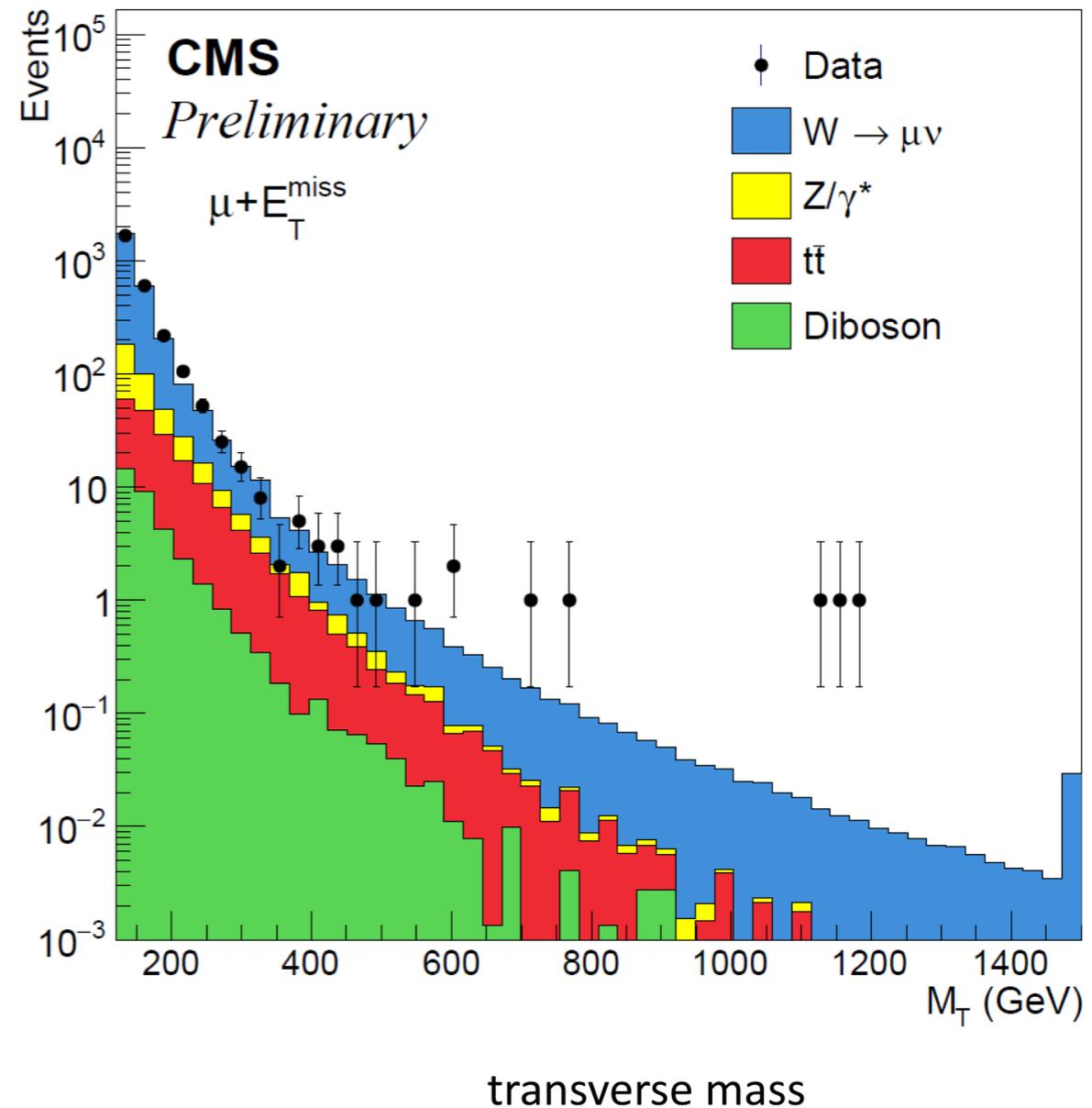
Good-quality isolated high- $p_T$  muon with  $p_T > 55$  GeV and  $|\eta| < 2.4$

## Event selection

- Single high- $p_T$  muon accompanied by a large missing transverse energy ( $E_T^{\text{miss}}$ ).
- Events containing additional muons with  $p_T > 25$  GeV are vetoed
- Kinematic selection:  
 $0.4 < p_T(\mu) / E_T^{\text{miss}} < 1.5$   
 $\Delta\Phi(\mu, E_T^{\text{miss}}) > 2.5$

Early Alignment used in data

42  $\text{pb}^{-1}$  (13 TeV)

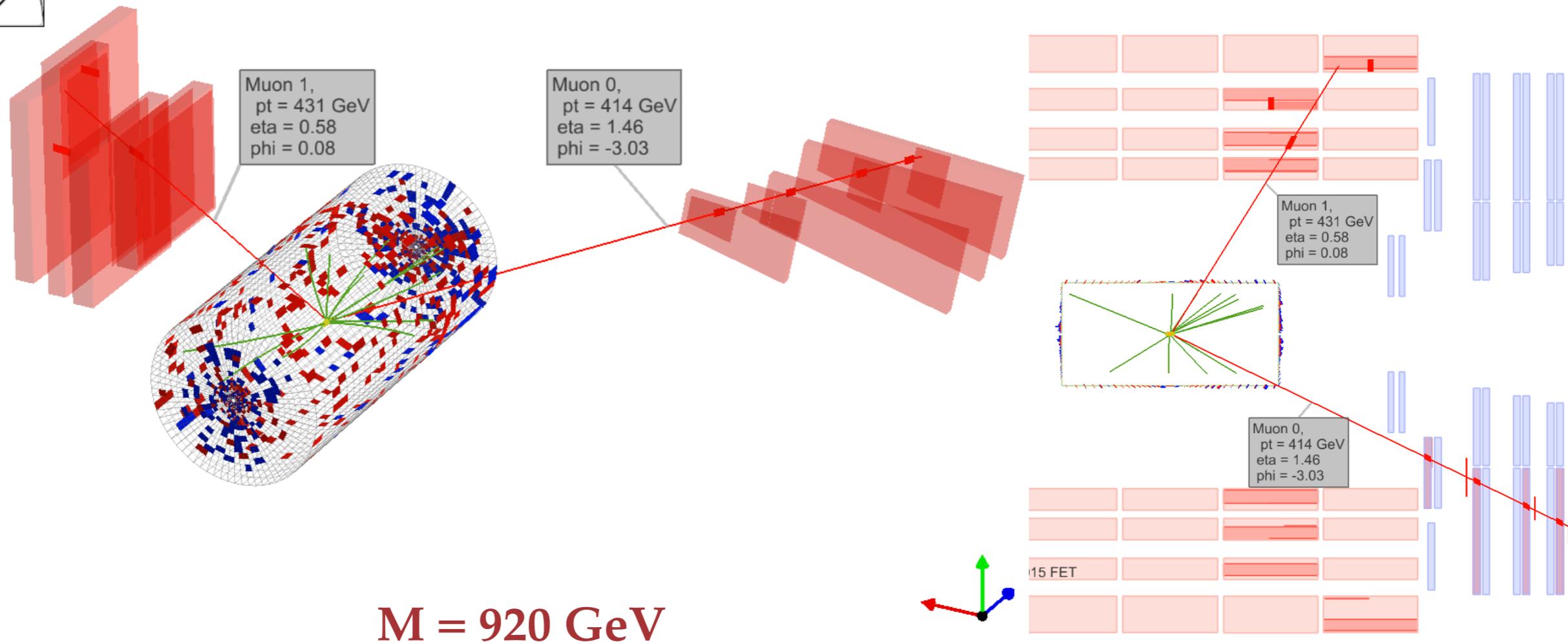


last bin includes overflow

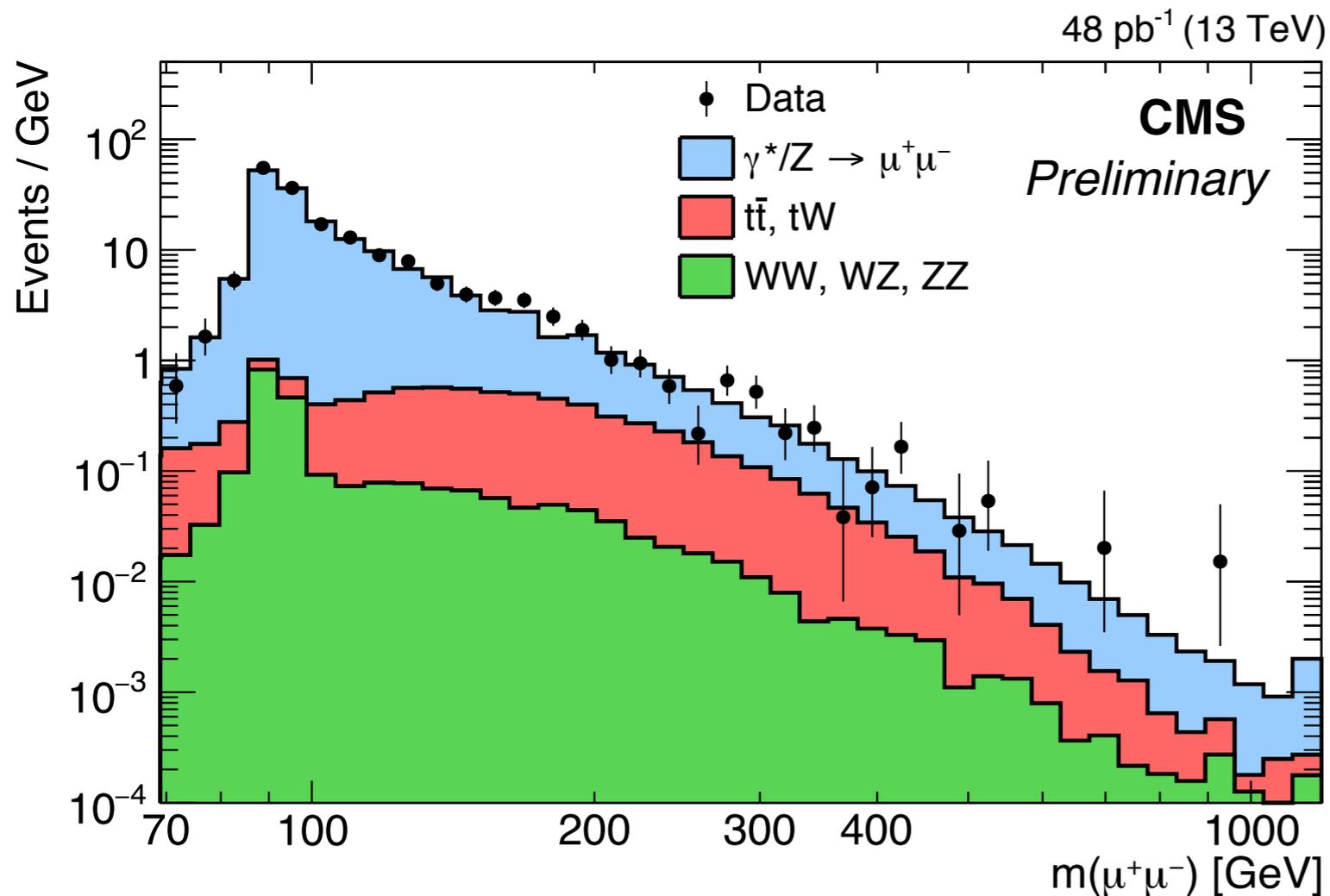
# Di-muon resonance search



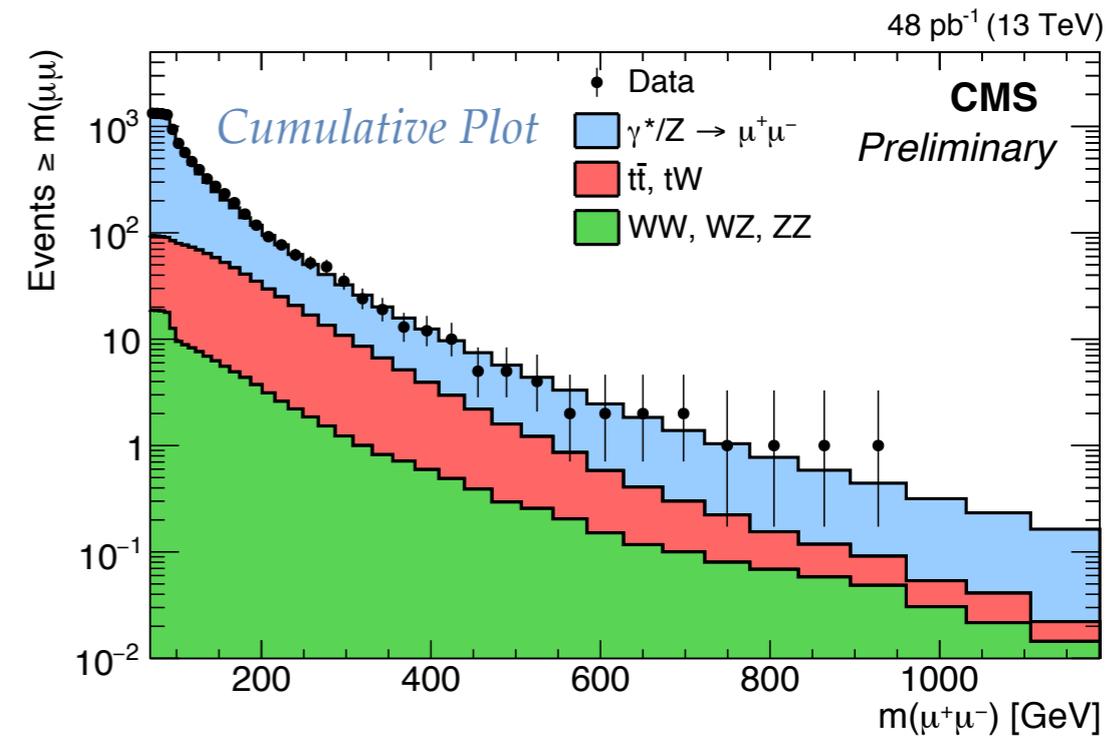
CMS Experiment at LHC, CERN  
Data recorded: Sun Jul 12 10:18:52 2015 FET  
Run/Event: 251562 / 367325039  
Lumi section: 414



# Di-muon resonance search



last bin includes overflow



Highest mass event = 920 GeV

Early alignment of Muon system  
and Tracker used in data

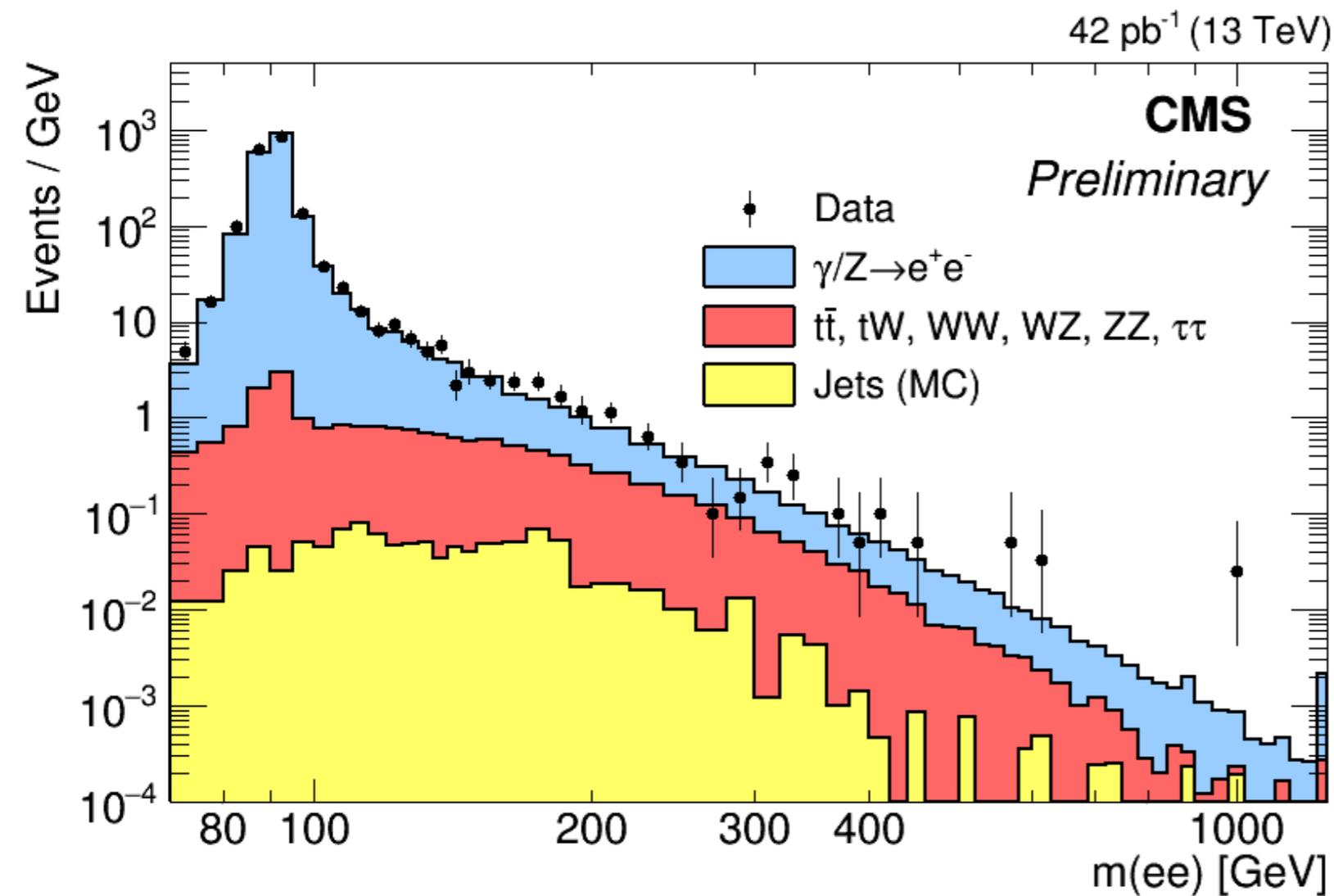
contribution from di-jets  
negligible and not shown

2 isolated muons muons are required to satisfy:

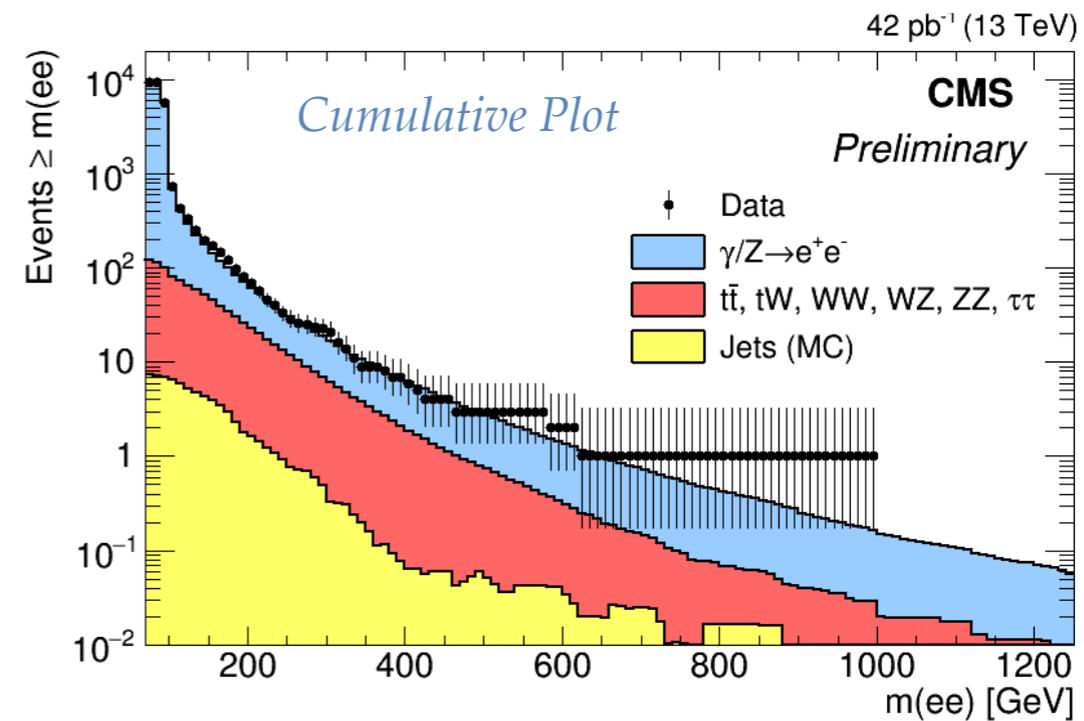
$$p_T > 48 \text{ GeV and } |\eta| < 2.4$$

MC samples: aMC@NLO for Drell-Yan, POWHEG for  $t\bar{t}$  and dibosons

# Di-electron resonance search



last bin includes overflow



Highest mass event  $\sim 1$  TeV

Run1 Limit for SSM  $Z'$   $< 2.9$  TeV

Run1 sensitivity will be reached  
 after about 2 fb<sup>-1</sup>

2 electrons in ECAL with  $E_T > 35$  GeV and at least one electron in the ECAL barrel

( $|\eta| < 1.4442$  or  $1.566 < |\eta| < 2.5$  with one electron within  $|\eta| < 1.4442$ )

# Di-electron resonance search

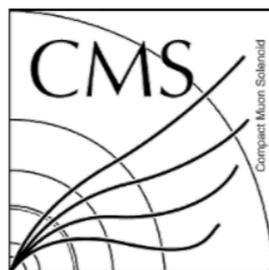
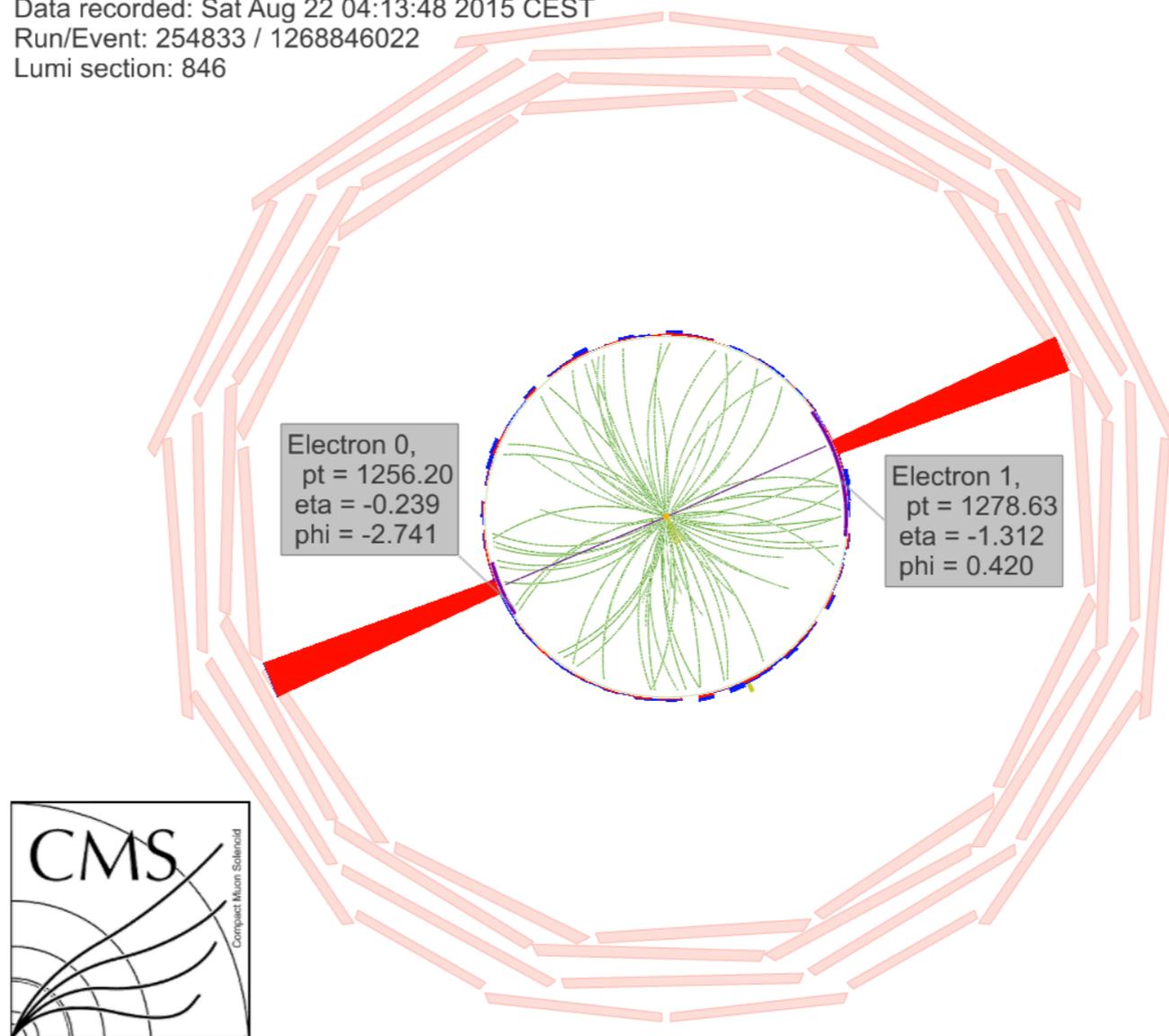
In the additional 25 pb<sup>-1</sup> data @13 TeV and 50 ns processed last Wednesday:

**An event with a di-electron mass of 2.9 TeV has been observed**

The event consists in two perfectly balanced electrons and no other significant activity

CMS Experiment at LHC, CERN  
Data recorded: Sat Aug 22 04:13:48 2015 CEST  
Run/Event: 254833 / 1268846022  
Lumi section: 846

**M = 2.9 TeV !!!**

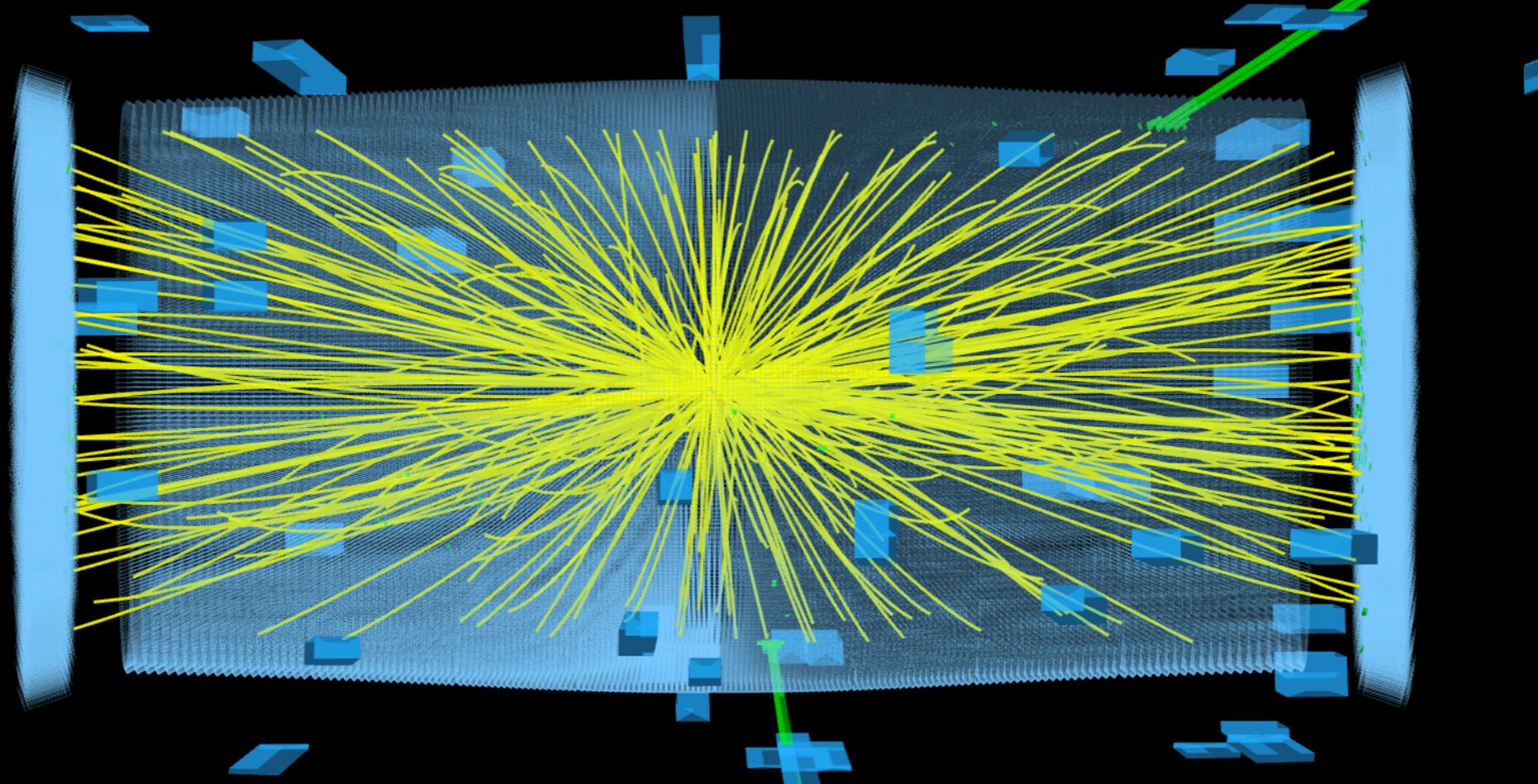




CMS Experiment at the LHC, CERN

Data recorded: 2015-Aug-22 02:13:48.861952 GMT

Run / Event / LS: 254833 / 1268846022 / 846



**M = 2.9 TeV !!!**

# Di-electron resonance search

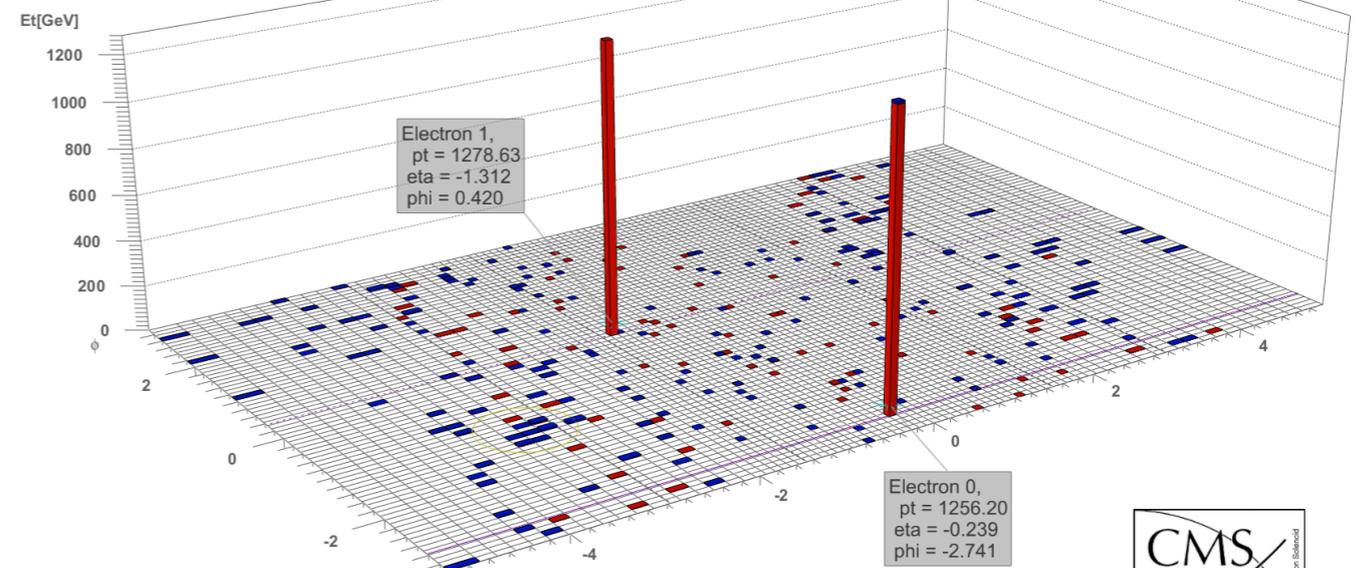
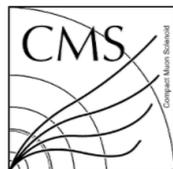
**M = 2.9 TeV !!!**

CMS Experiment at LHC, CERN  
Data recorded: Sat Aug 22 04:13:48 2015 CEST  
Run/Event: 254833 / 1268846022  
Lumi section: 846

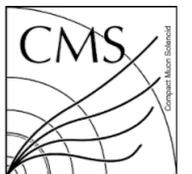


Electron 1,  
pt = 1278.63  
eta = -1.312  
phi = 0.420

Electron 0,  
pt = 1256.20  
eta = -0.239  
phi = -2.741

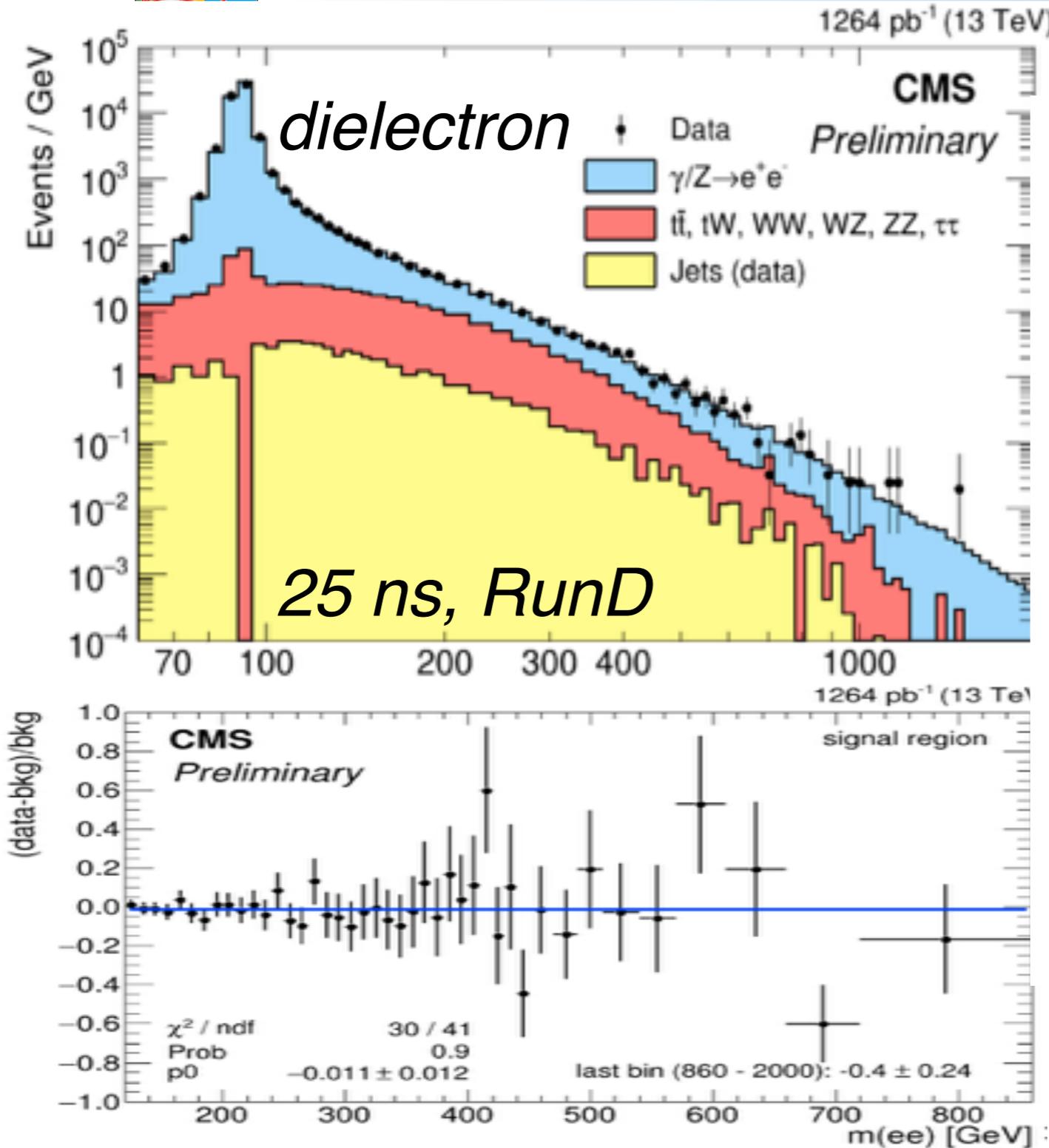


CMS Experiment at LHC, CERN  
Data recorded: Sat Aug 22 04:13:48 2015 CEST  
Run/Event: 254833 / 1268846022  
Lumi section: 846

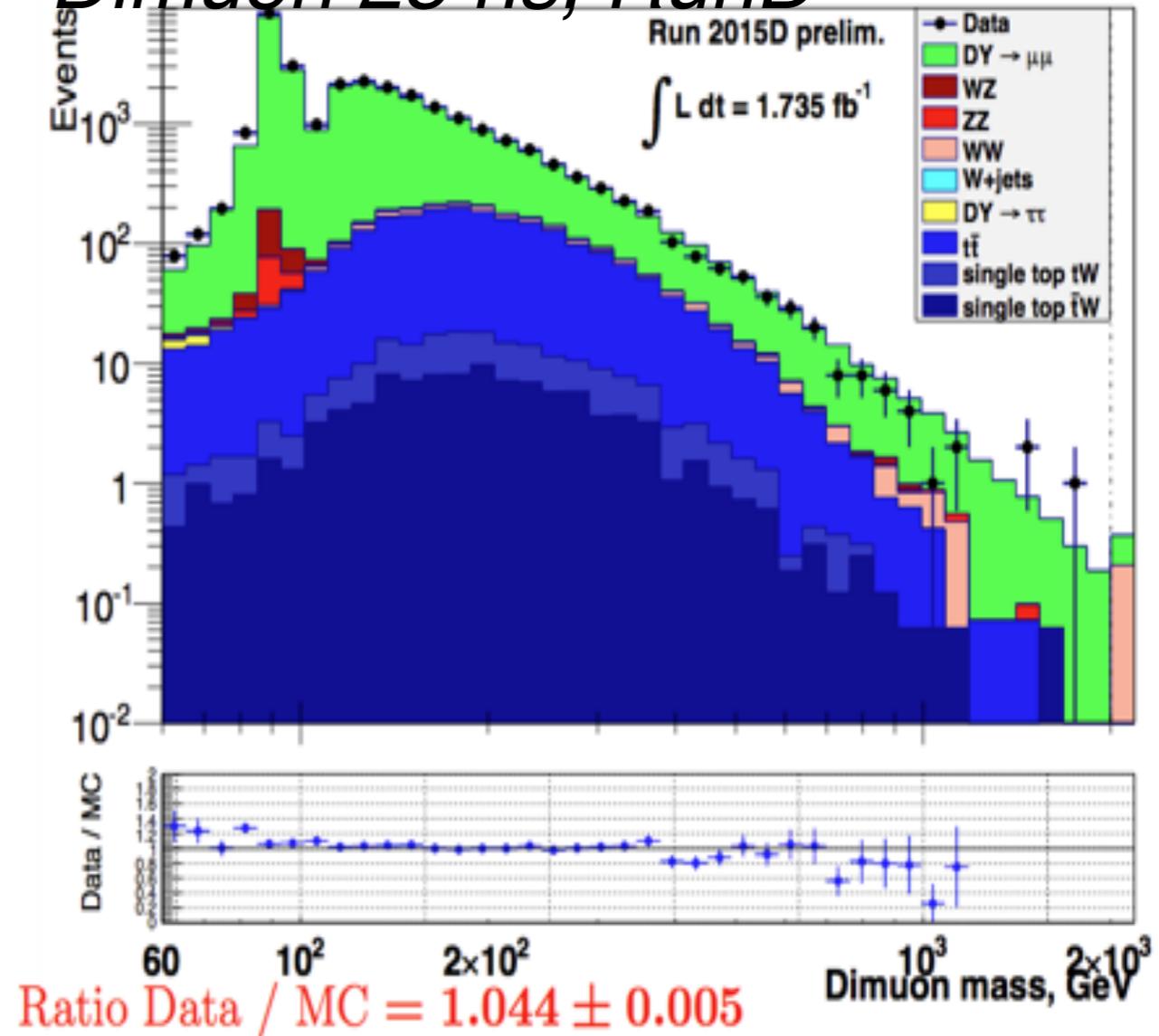




# Drell-Yan pairs - Dilepton spectra

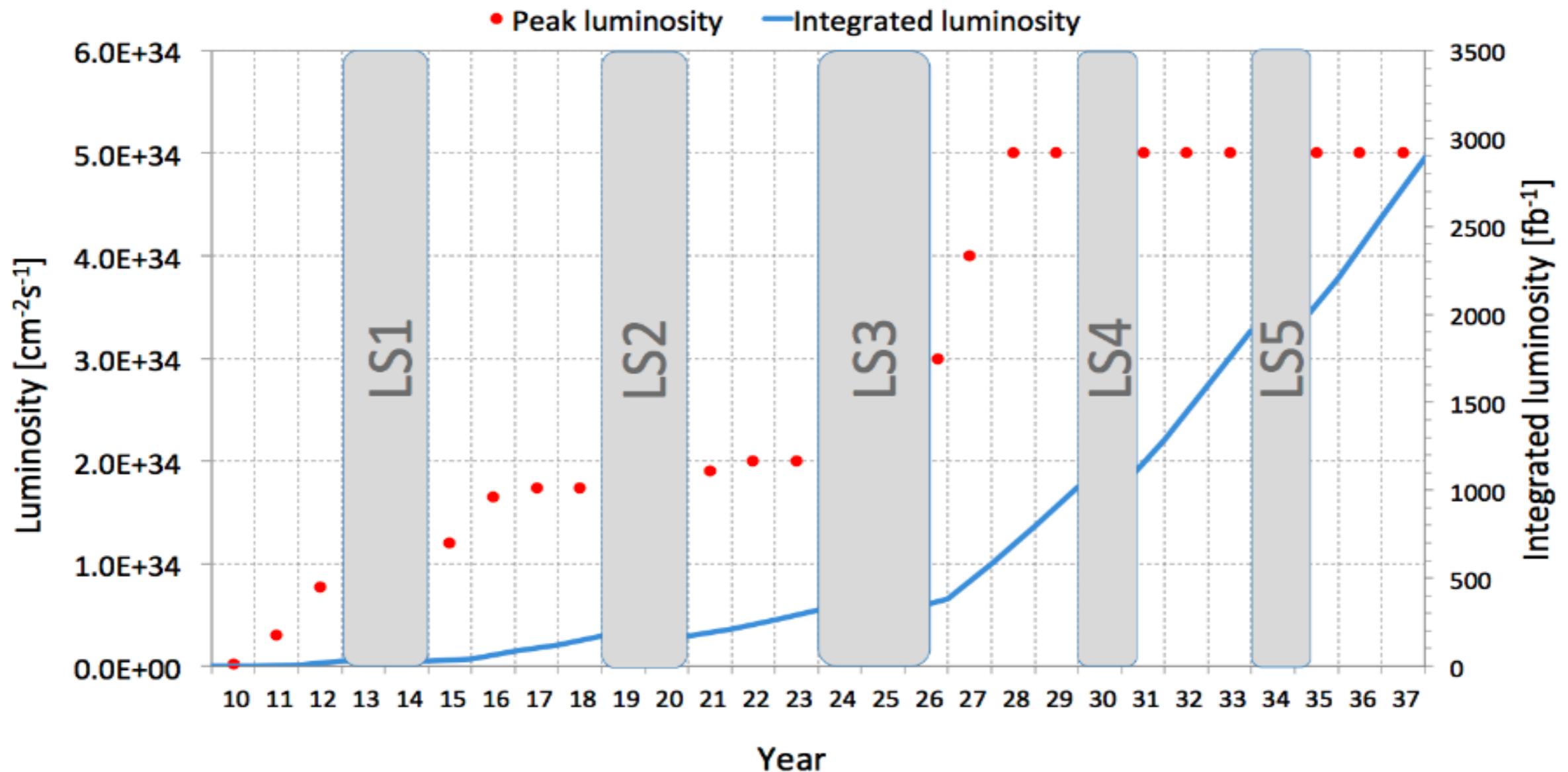


## Dimuon 25 ns, RunD



**No new events at 2.9 TeV**

- $3000 \text{ fb}^{-1}$  is the target integrated luminosity
- $5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$   $\rightarrow$  140 Pile-up is the nominal peak luminosity
- $7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$   $\rightarrow$  200 Pile-up is the ultimate peak luminosity ( $>$ LS4)





# But ... Cryogenics problem

- Since March 2015 the “Cold Box” (CB) that produces liquid He for the operation of the CMS magnet has had problems, following a compressor oil pollution of the CB circuit.
- For a definitive recovery, the system requires an overall cleanup which takes several months.
- Meanwhile, the CERN cryogenics group, in collaboration with the CMS Technical Coordination group, has been trying to find a way to operate the Cold Box with a reasonable Duty Cycle ( $> 70\%$ ) that would allow operation of the magnet synchronized with physics operation of the LHC until the Year End Technical Stop.
- During TS2: augmented surface filters were installed; in addition, a special “regeneration cycle” has resulted in allowing a continued magnet operation since.