



# CMS

# Recent Results and Status



# Content

- **Status – Run II**
- **Detector – Run I**
- **Results – Run I**
- **Long Shutdown I**
- **Outlook**



# Status – Run II



# LHC schedule

towards first collisions ...

Start LHC commissioning  
with beam

V1.4

Scrubbing for 50ns  
operation

Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo		30	Easter Mon	6	13	20	27	4	11	18	Whit	25	1
Tu													
We			Injector TS										
Th	Machine checkout								Ascension				
Fr													
Sa					1st May								
Su				today									



# Status Experiments

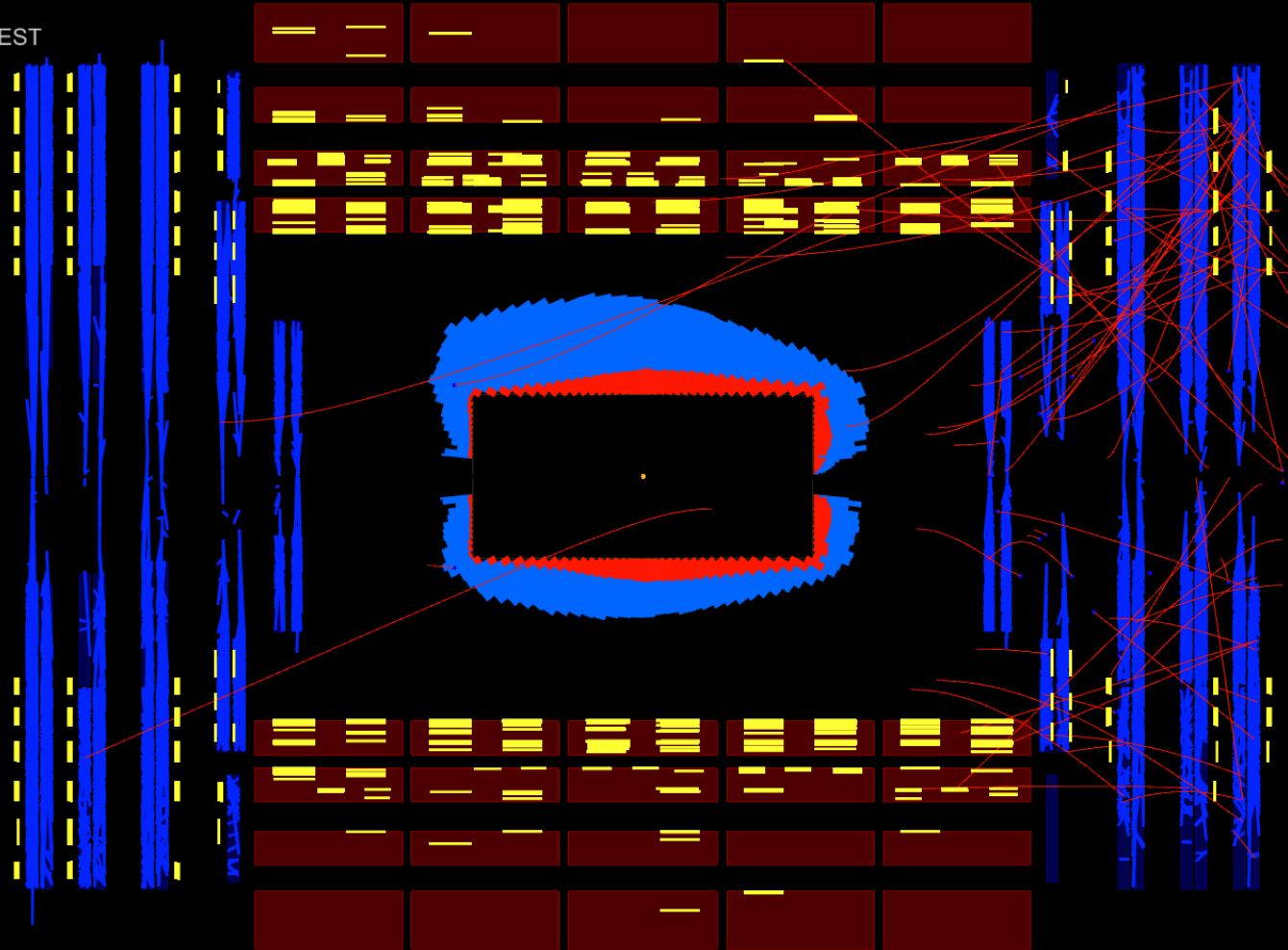
15-Apr-2015 13:51:15	Fill #: 3622	Energy: 0 GeV	I(B1): 0.00e+00	I(B2): 0.00e+00
Experiment Status	ATLAS	ALICE	CMS	LHCb
Instantaneous Lumi [(ub.s)^{-1}]	STANDBY	STANDBY	STANDBY	CALIBRATION
BRAN Luminosity [(ub.s)^{-1}]	0.039	0.000	-	404.386
Fill Luminosity (nb)^{-1}	9.9	0.0	0.9	0.0
BKGD 1	0.000	0.000	-	0.000
BKGD 2	0.002	0.000	0.750	0.131
BKGD 3	0.018	0.020	0.250	0.000
LHCb VELO Position	OUT	Gap: 58.0 mm	NO BEAM	TOTEM: STANDBY

CMS ready, waiting ...



# First Splash Events

CMS Experiment at LHC, CERN  
Data recorded: Sun Apr 5 10:29:07 2015 CEST  
Run/Event: 239754 / 162  
Lumi section: 89

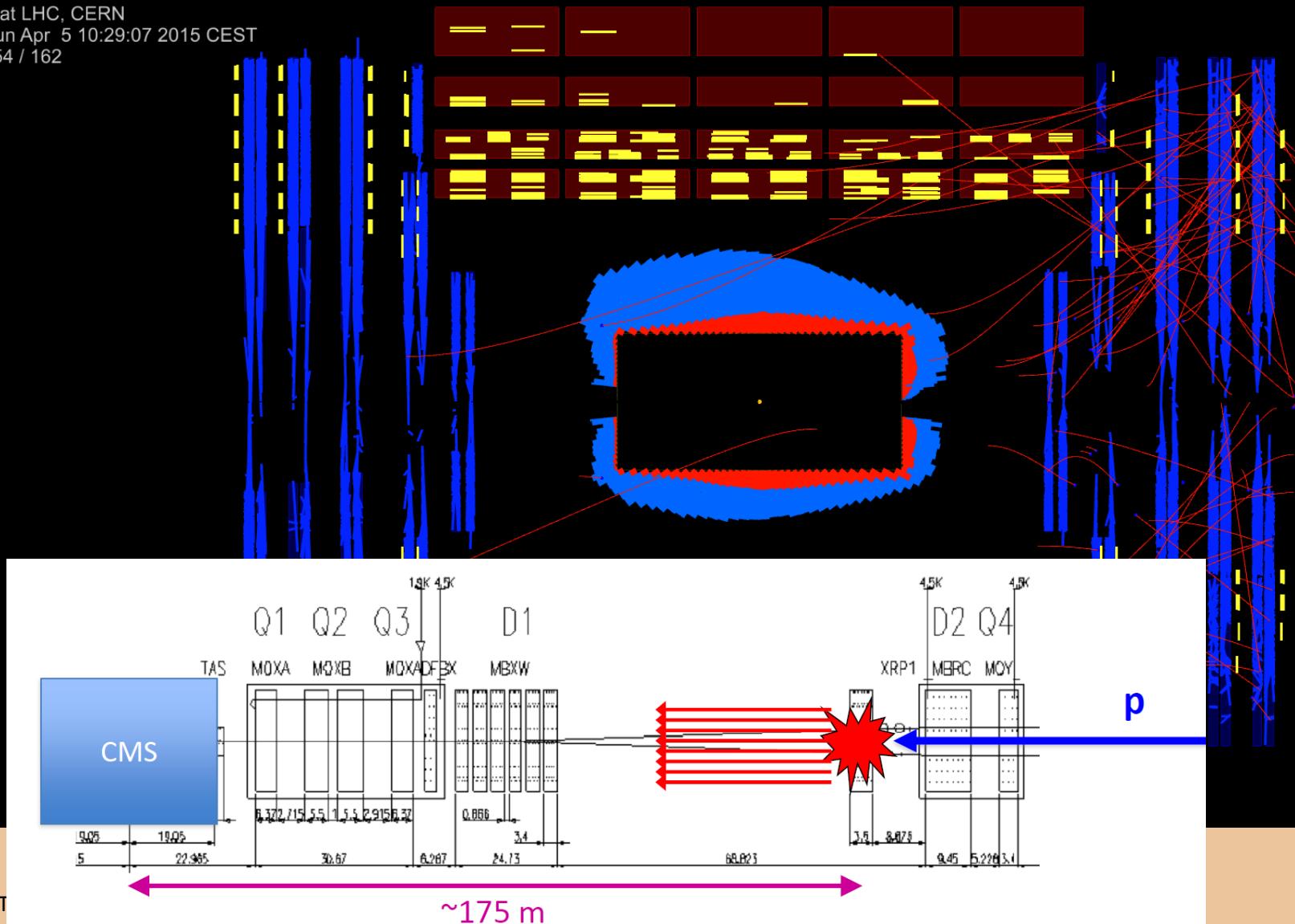


,splash event': first particles seen in CMS



# First Splash Events

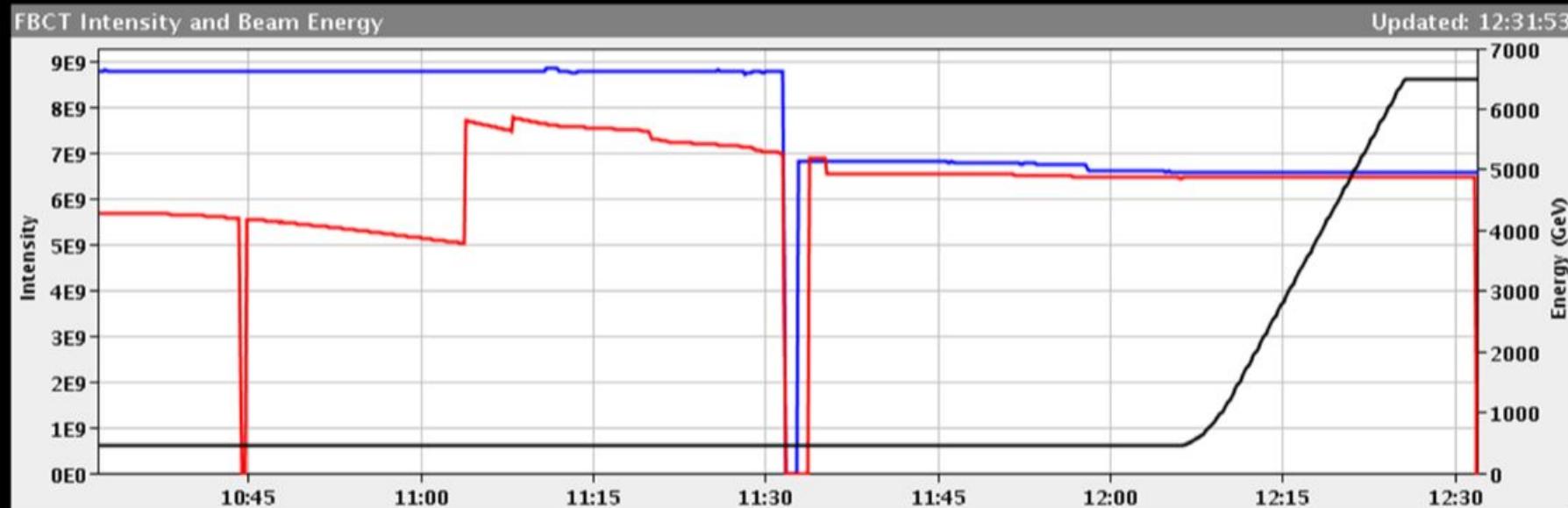
CMS Experiment at LHC, CERN  
Data recorded: Sun Apr 5 10:29:07 2015 CEST  
Run/Event: 239754 / 162  
Lumi section: 89





# A New Record Energy

Energy: 6500 GeV I(B1): 5.34e+09 I(B2): 7.64e+07



BIS status and SMP flags		B1	B2
Comments (11-Apr-2015 12:29:40)	Both beams up at 6.5 TeV!!!	Link Status of Beam Permits	false false
		Global Beam Permit	true false
		Setup Beam	true true
		Beam Presence	true false
		Moveable Devices Allowed In	false false
		Stable Beams	false false

AFS: alternating R1 R2 pilot

PM Status B1

ENABLED

PM Status B2

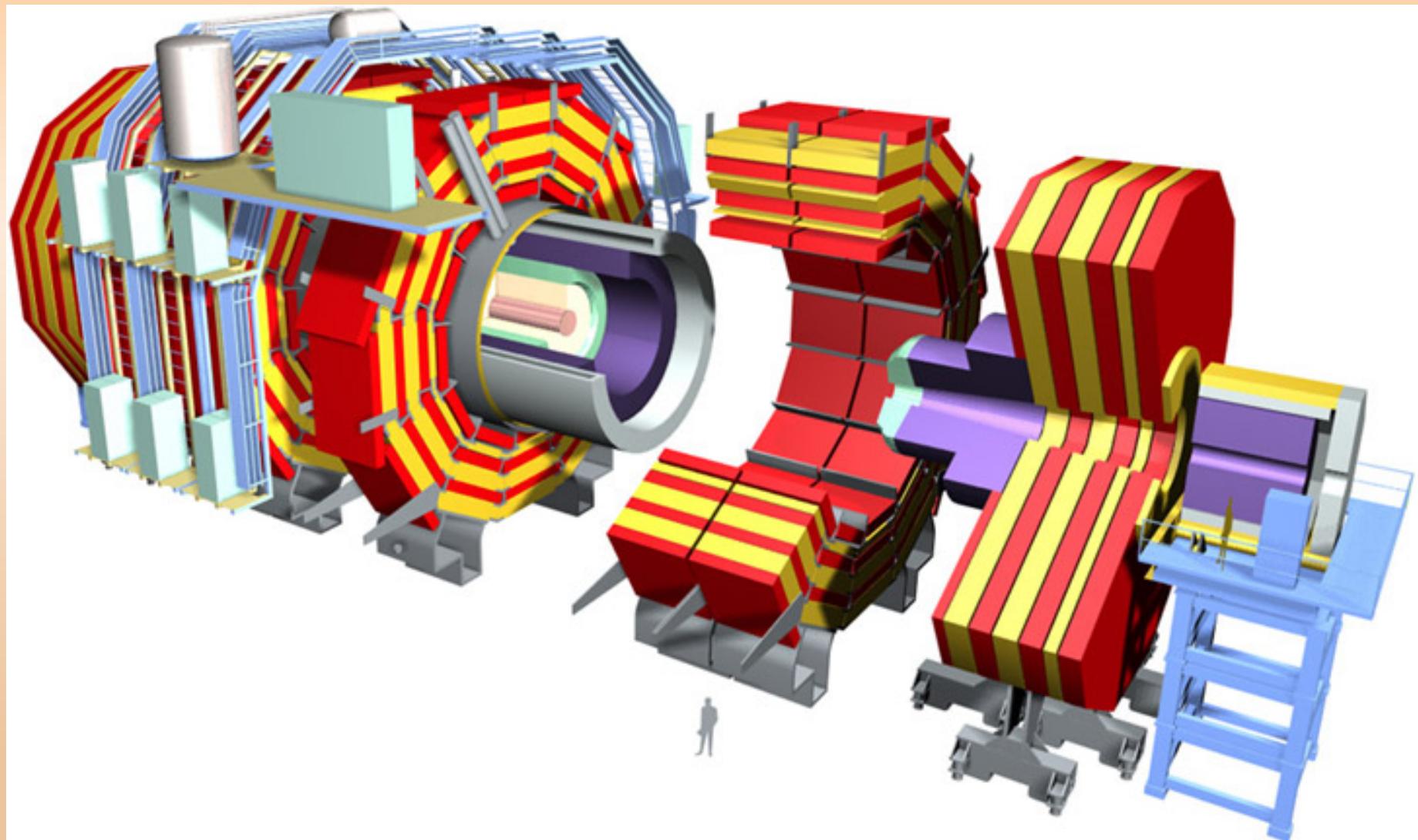
ENABLED



# Detector – Run I

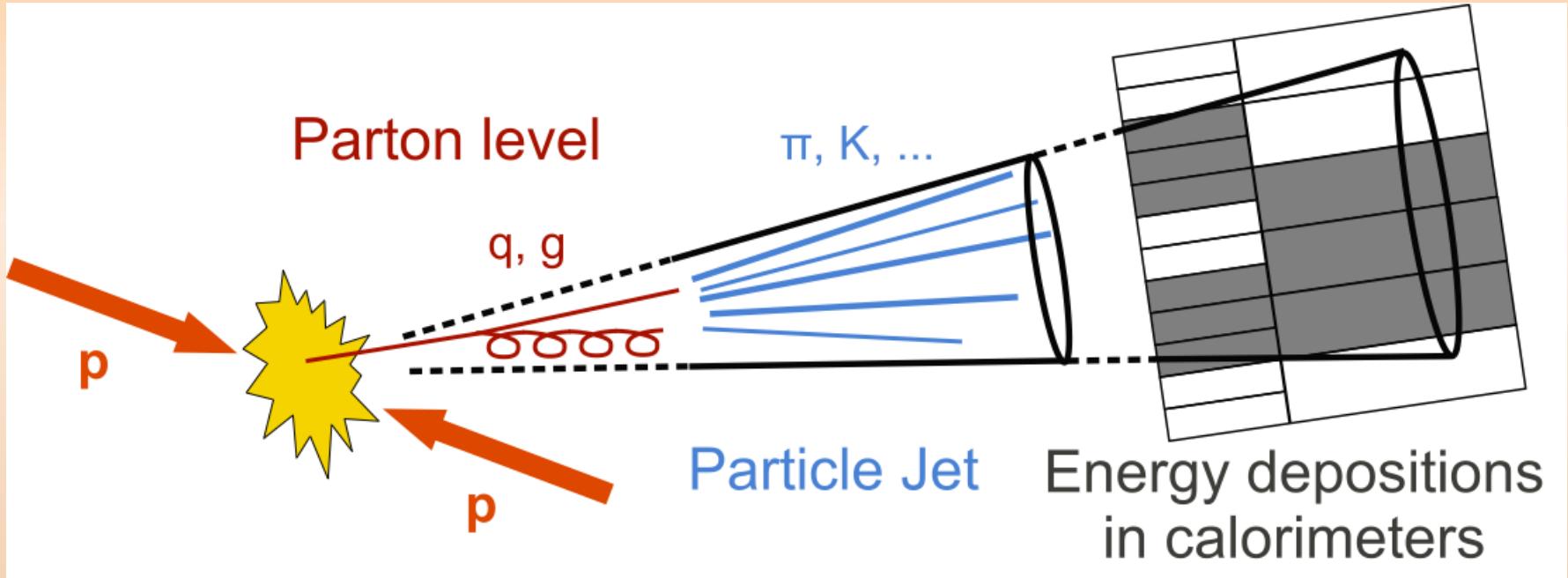


# The CMS Detector





# Particle Flow



Classical Jets:

$$E_j = E_{E\text{Cal}} + E_{H\text{Cal}}$$

Particle Flow:

$$E_j = E(\text{tracks}) + E(\text{photons}) + E(\text{neut. hadrons})$$

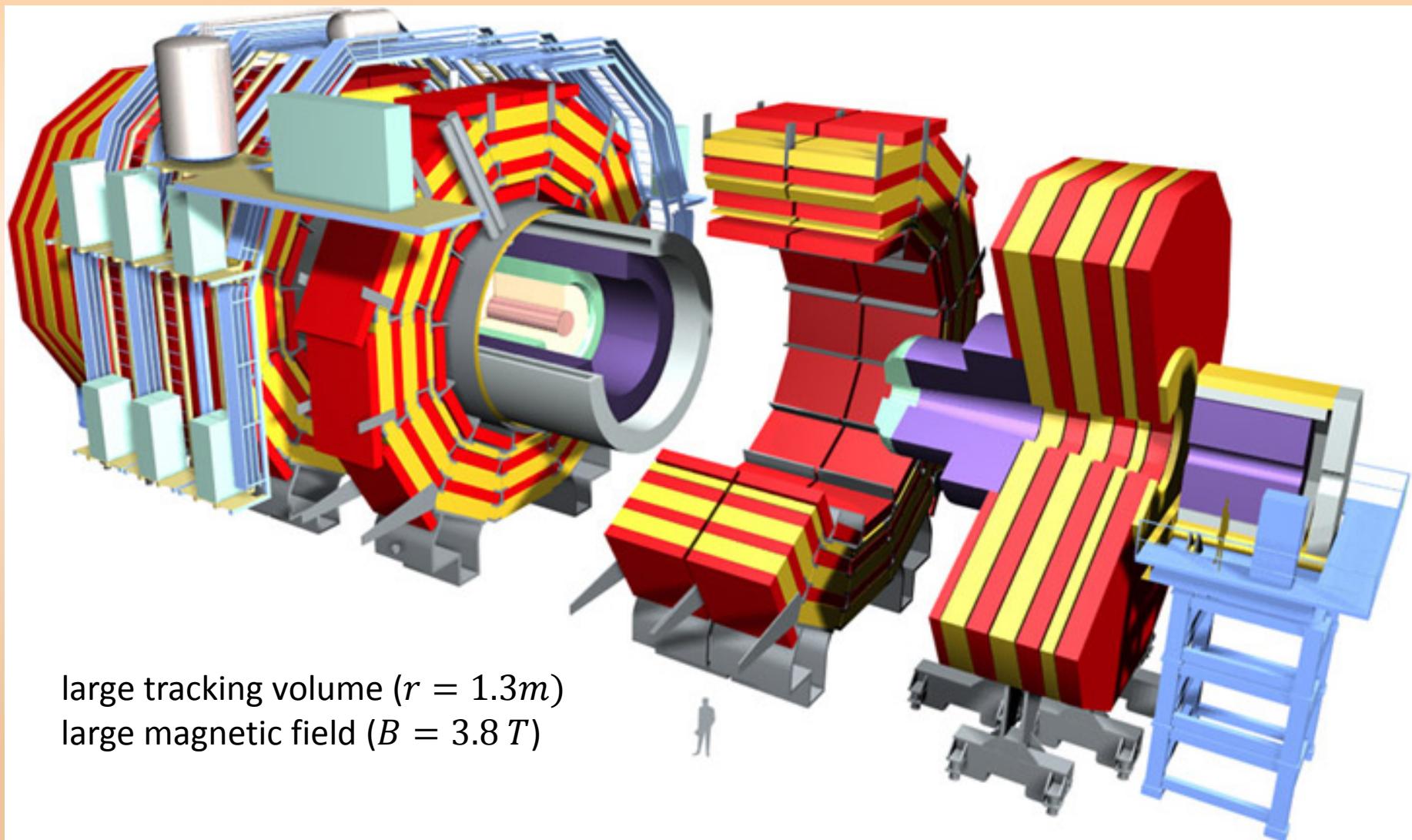
tracker  
~60%

ECal  
~30%

HCal  
~10%



# The CMS Detector



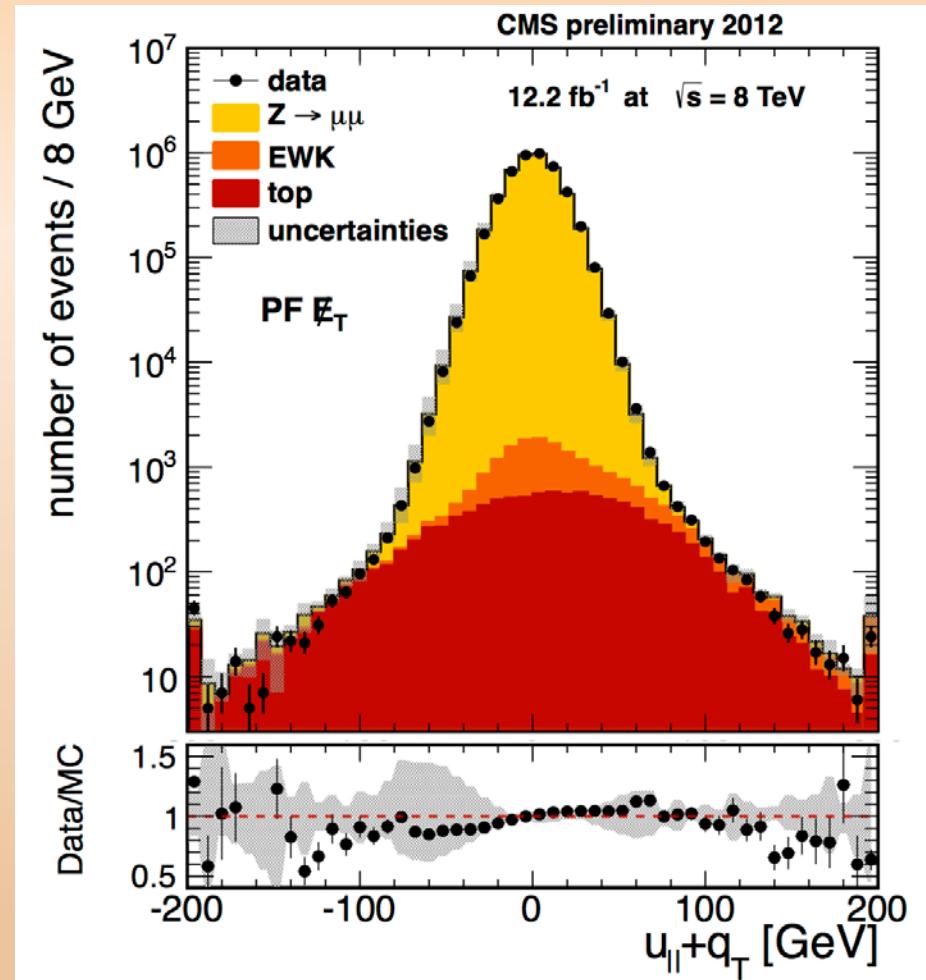
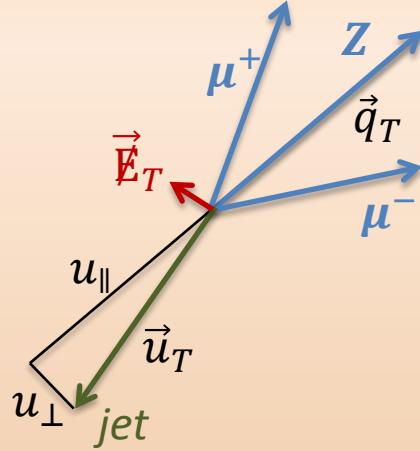
large tracking volume ( $r = 1.3m$ )  
large magnetic field ( $B = 3.8 T$ )



# Jet Energy Resolution

Performance (example):

$$pp \rightarrow Z + j$$

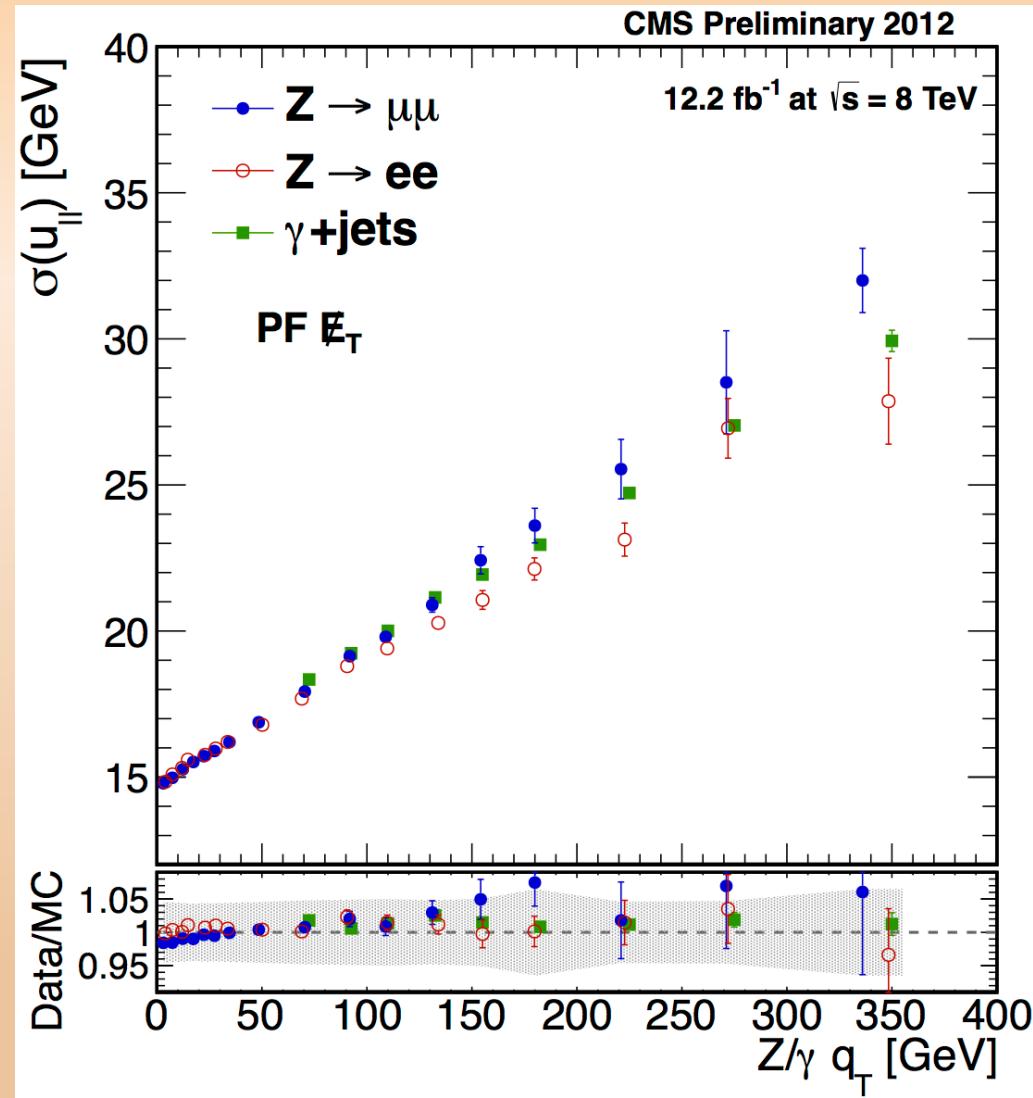
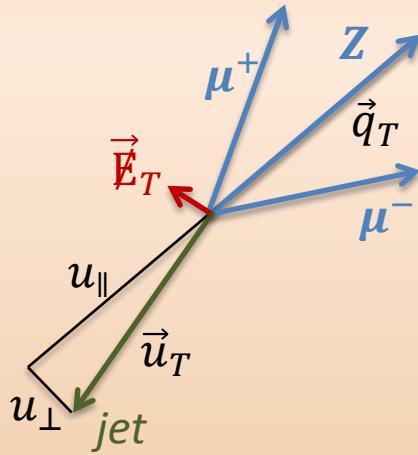




# Jet Energy Resolution

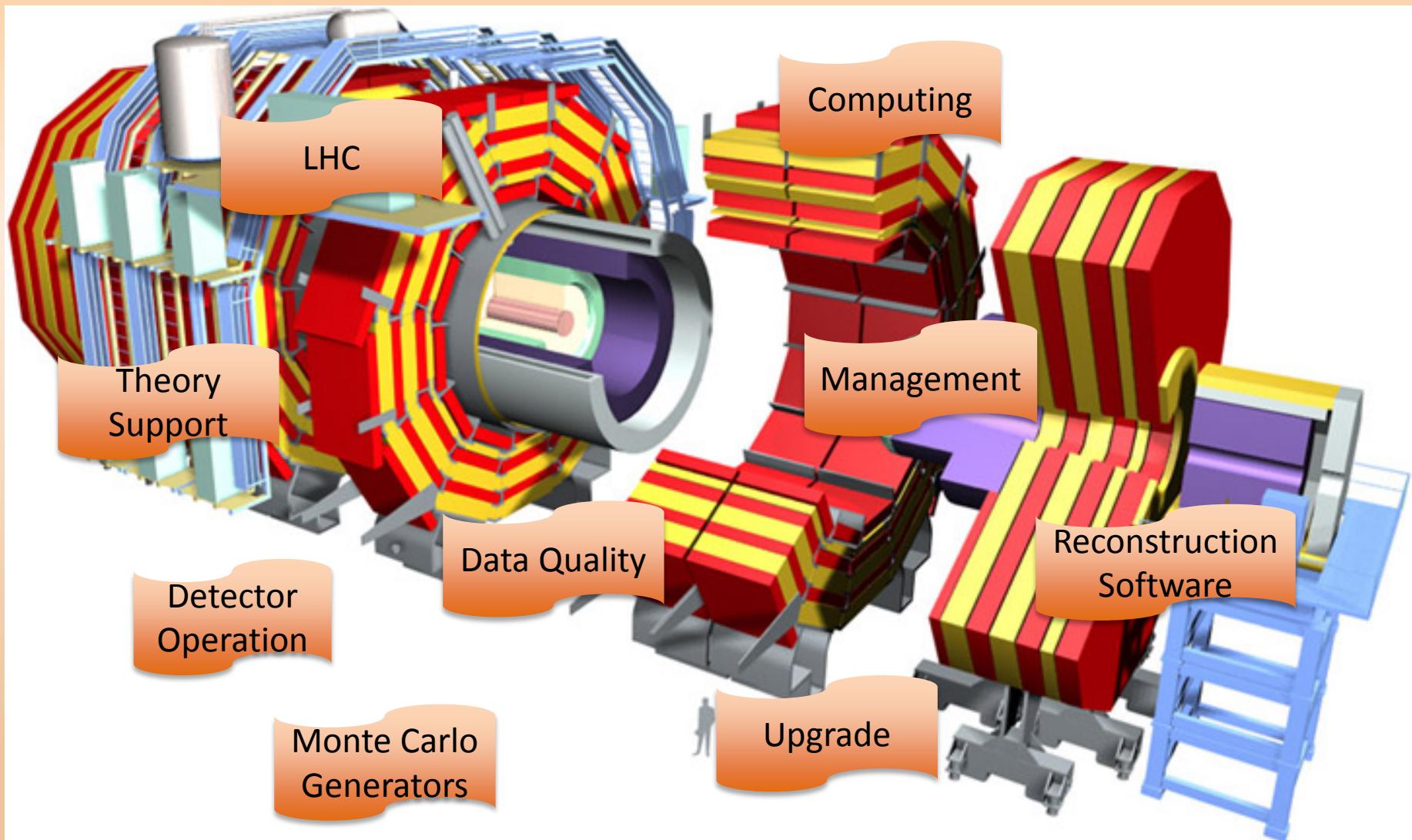
Performance (example):

$$pp \rightarrow Z + j$$





# The CMS Detector





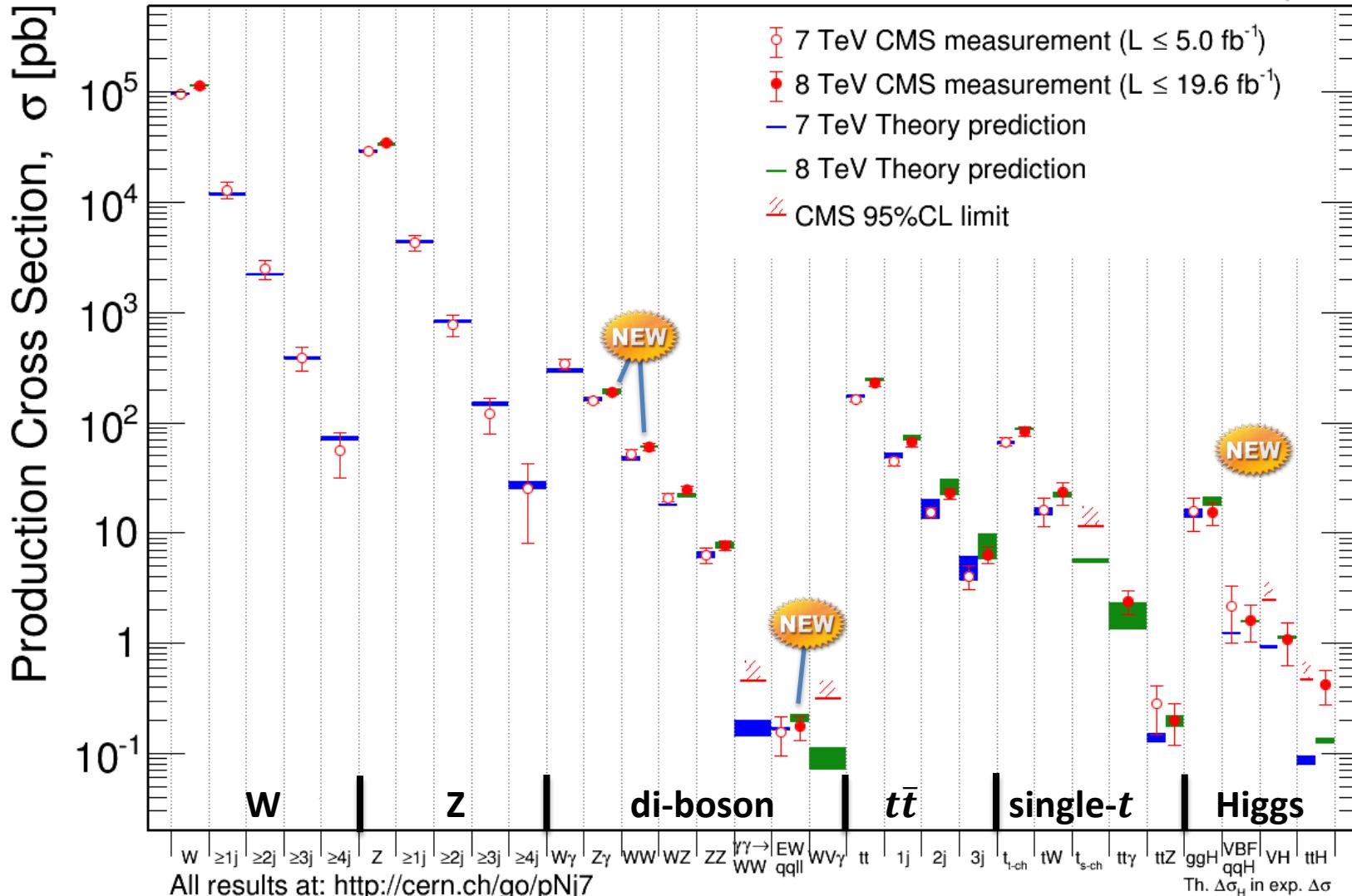
# Results – Run I



# SM cross sections

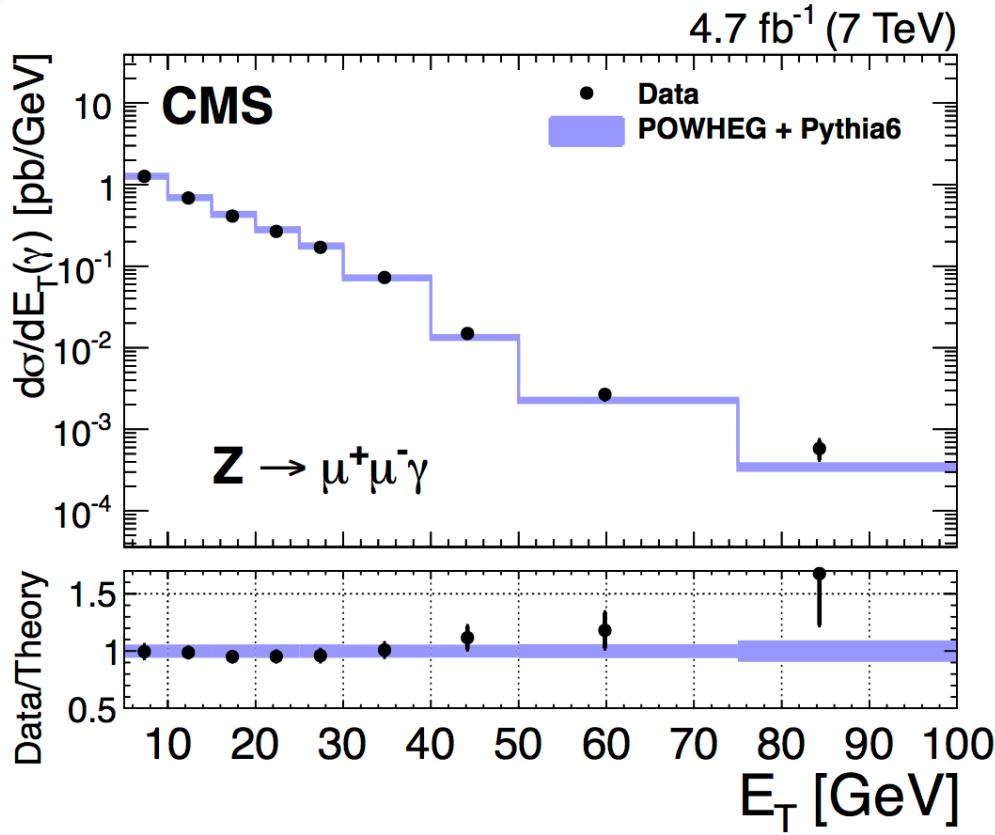
Mar 2015

CMS Preliminary





# SM cross sections: $Z \rightarrow \mu\mu\gamma$



Differential cross section:  
Mainly FSR from the  $Z$

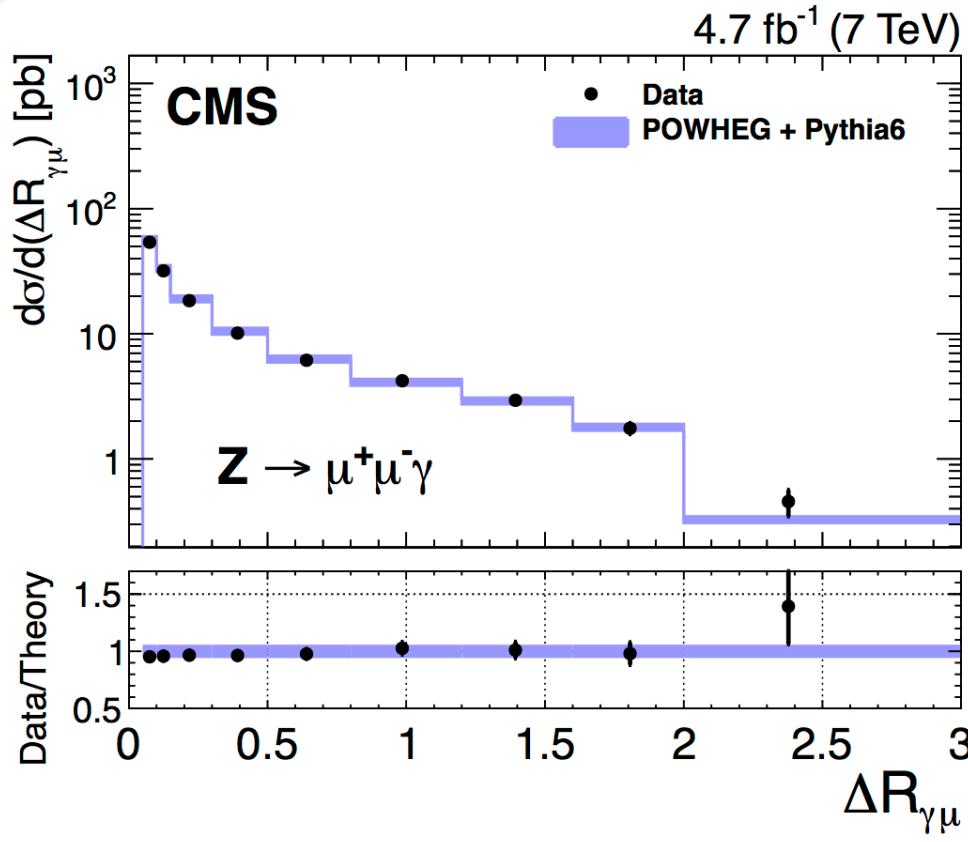
1. Transverse energy of  
the photon  
(with respect to the beam)

Kinematic selection:  
 $E_T(\gamma) > 5 \text{ GeV}$   
 $|\eta(\gamma)| < 2.4$   
 $0.05 < \Delta R_{\mu\gamma} \leq 3$   
 $30 < M_{\mu\mu} < 87 \text{ GeV}$

arXiv.1502.07940



# SM cross sections: $Z \rightarrow \mu\mu\gamma$



Differential cross section:  
Mainly FSR from the  $Z$

1. Transverse energy of  
the photon  
(with respect to the beam)
2. Separation from the  
closest muon

$$\Delta R_{\mu\gamma} = \sqrt{(\phi_\mu - \phi_\gamma)^2 + (\eta_\mu - \eta_\gamma)^2}$$

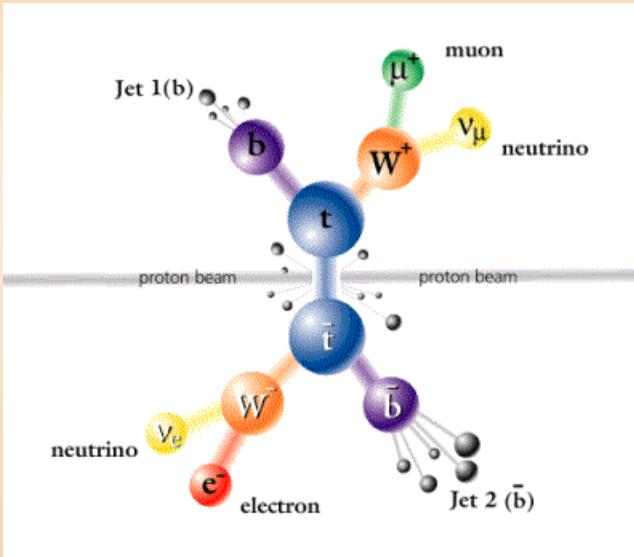
Kinematic selection:  
 $E_T(\gamma) > 5 \text{ GeV}$   
 $|\eta(\gamma)| < 2.4$   
 $0.05 < \Delta R_{\mu\gamma} \leq 3$   
 $30 < M_{\mu\mu} < 87 \text{ GeV}$

arXiv.1502.07940



# top-quark: mass

## di-leptonic events



Top Pair Decay Channels	
$\bar{c}s$	all-hadronic
$\bar{u}d$	electron+jets
$\tau^-$	muon+jets
$\mu^- \tau^+$	tau+jets
$e^-$	dileptons
$W$ decay	muon+jets
$e^+$	electron+jets
$\mu^+$	
$\tau^+$	
$u\bar{d}$	
$c\bar{s}$	

Kinematic observable:  $m_{\ell b}^2$

$$m_{\ell b}^2 = \frac{m_t^2 - m_W^2}{2} (1 - \cos \theta_{\ell b})$$

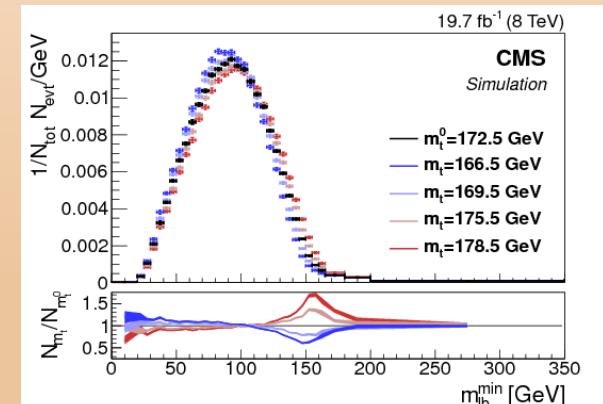
kinematic endpoint at

$$\max(m_{\ell b}) \approx \sqrt{m_t^2 - m_W^2}$$

Combinatorics: choose

- b-jet with max.  $p_T$
- $\ell$  which gives minimum  $m_{\ell b}$

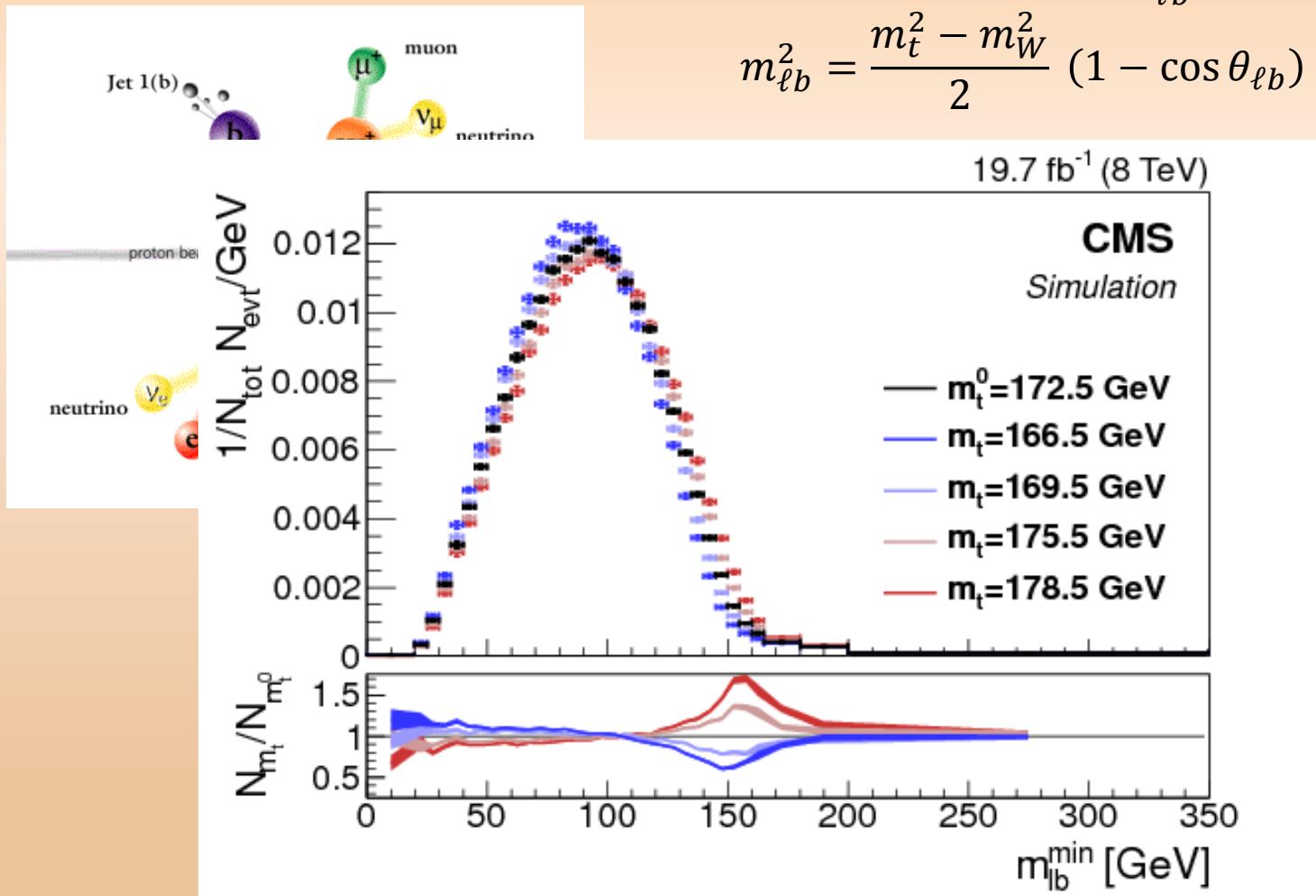
$$m_{\ell b}^{\min}$$



NEW  
Sept.'14

# top-quark: mass

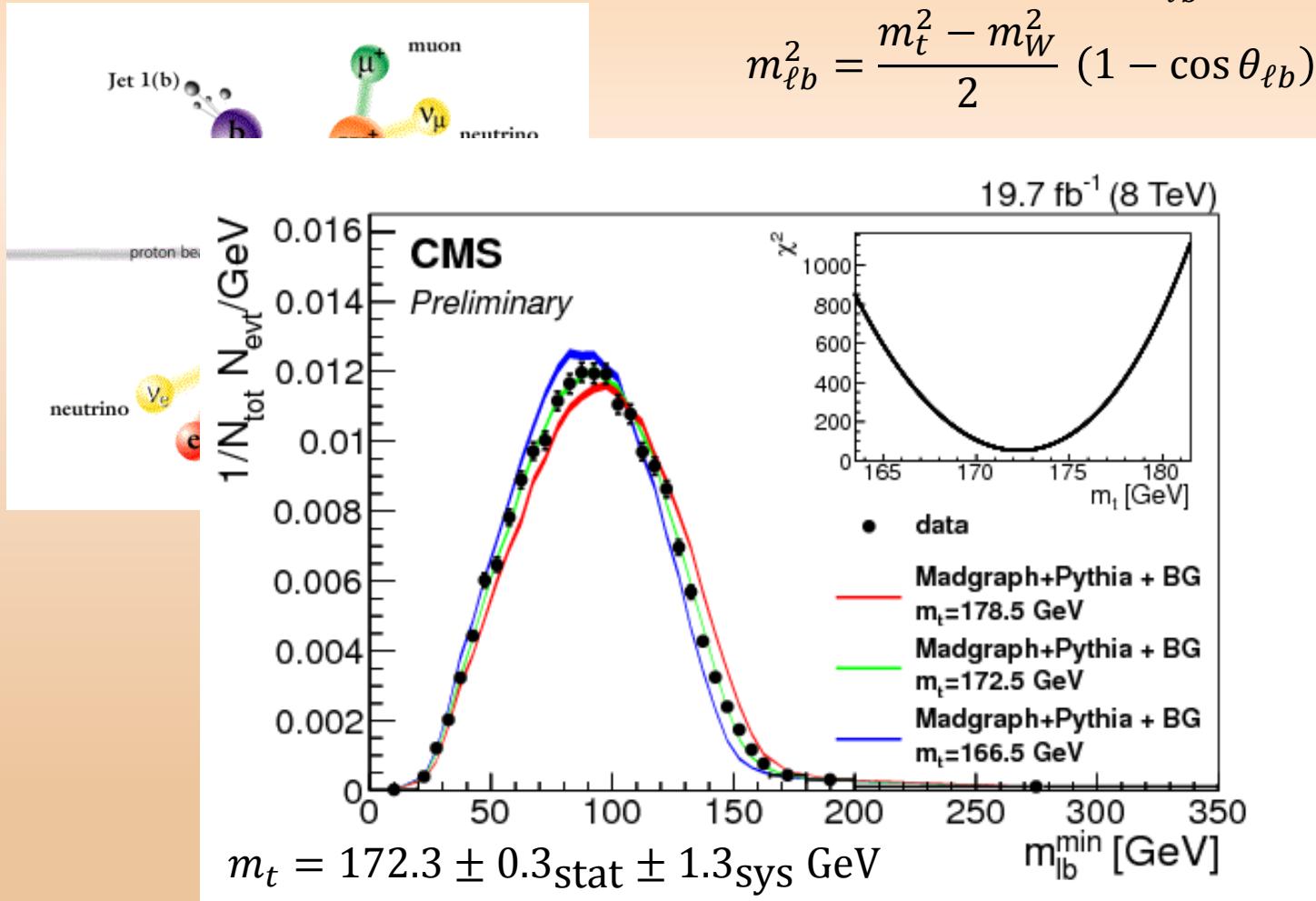
## di-leptonic events



**NEW**  
Sept.'14

# top-quark: mass

## di-leptonic events



**NEW**  
Sept.'14



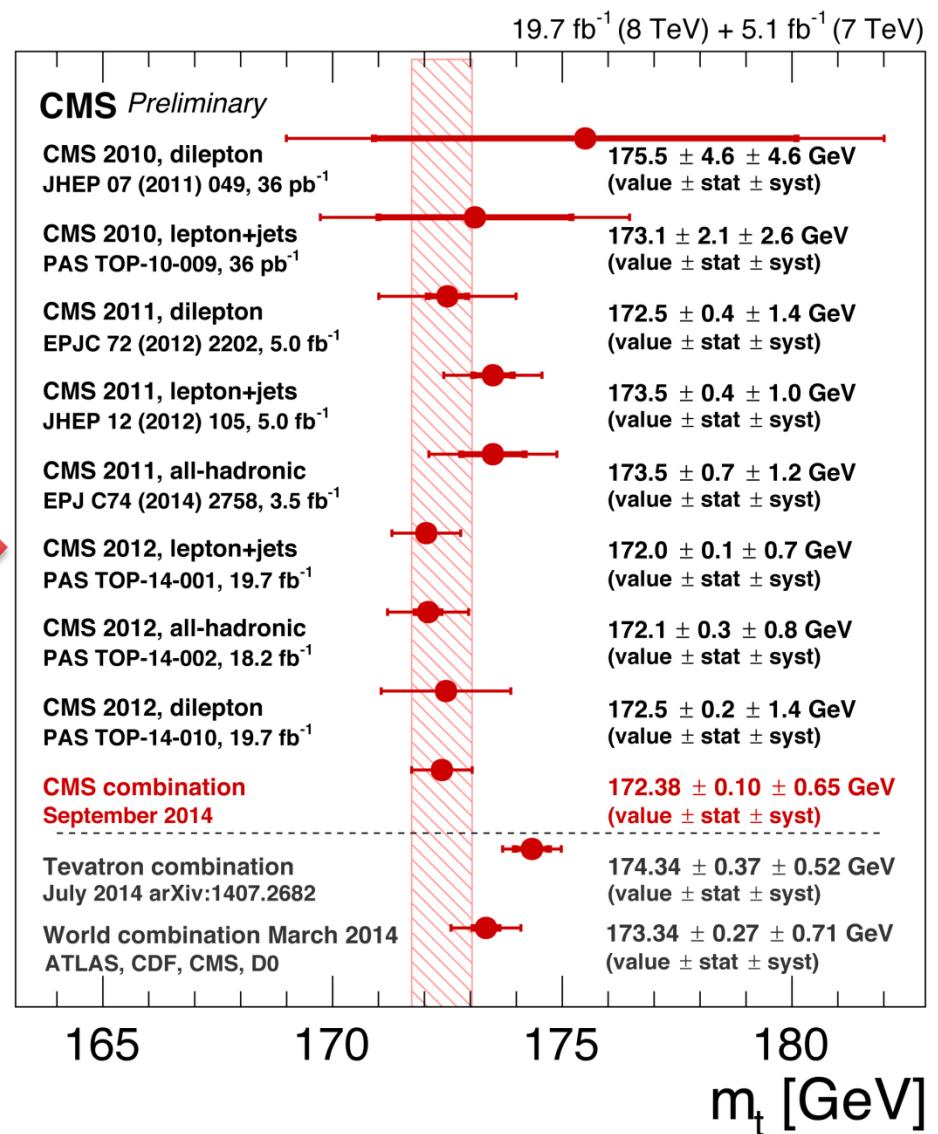
# top-quark: mass

Summary of previous measurements:

New measurement:  $m_{\ell b}^{\min}$

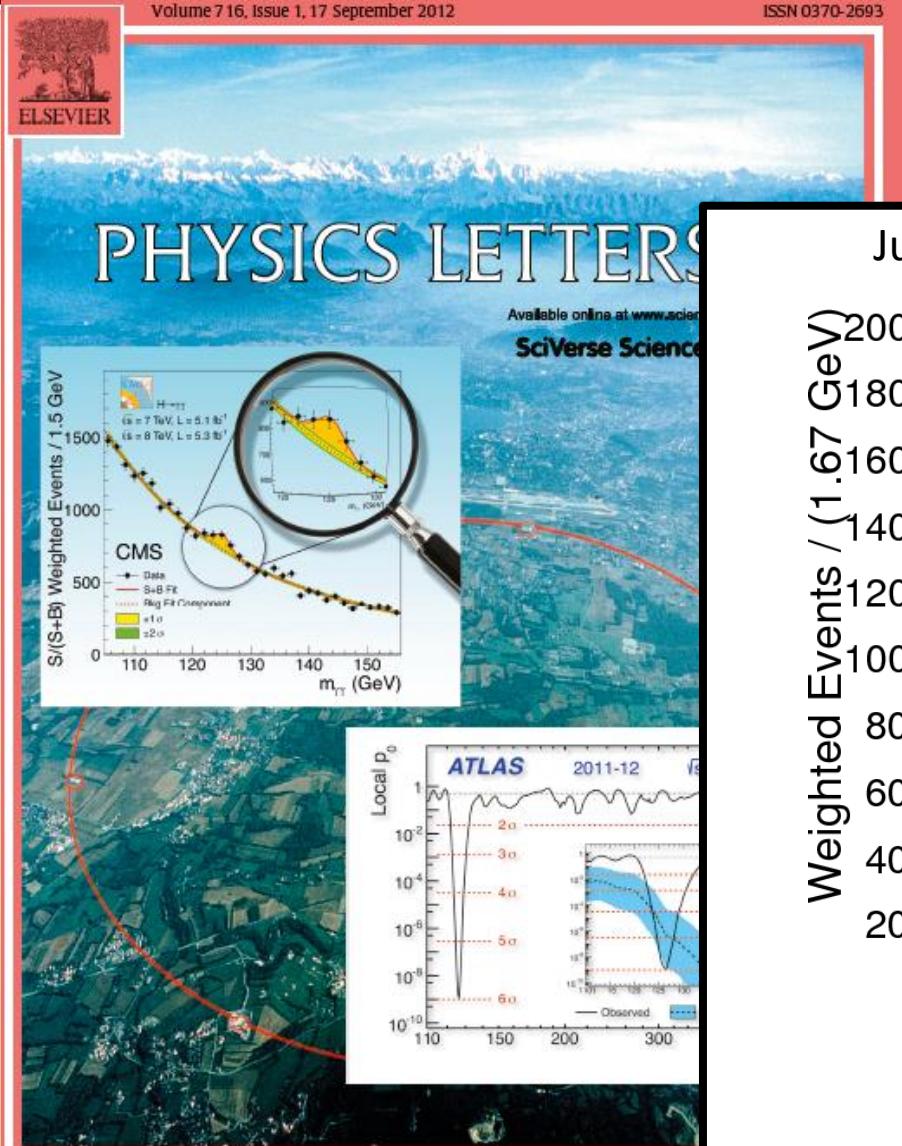
$$m_t = 172.3 \pm 0.3_{\text{stat}} \pm 1.3_{\text{sys}} \text{ GeV}$$

single  
most  
precise  
measurement



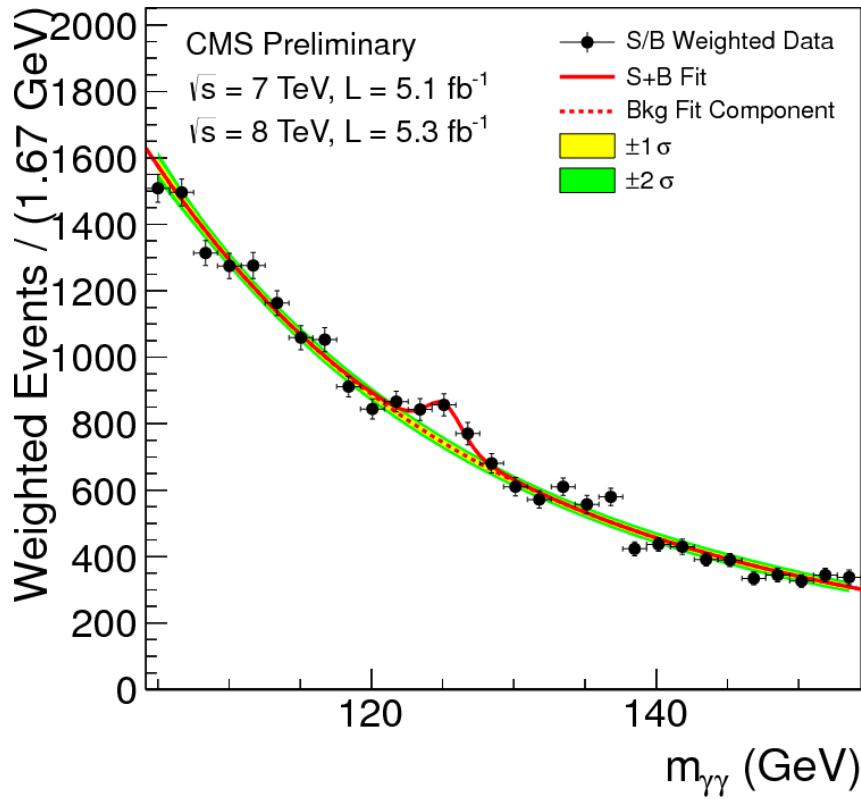


# The Higgs-Boson



What's new ?

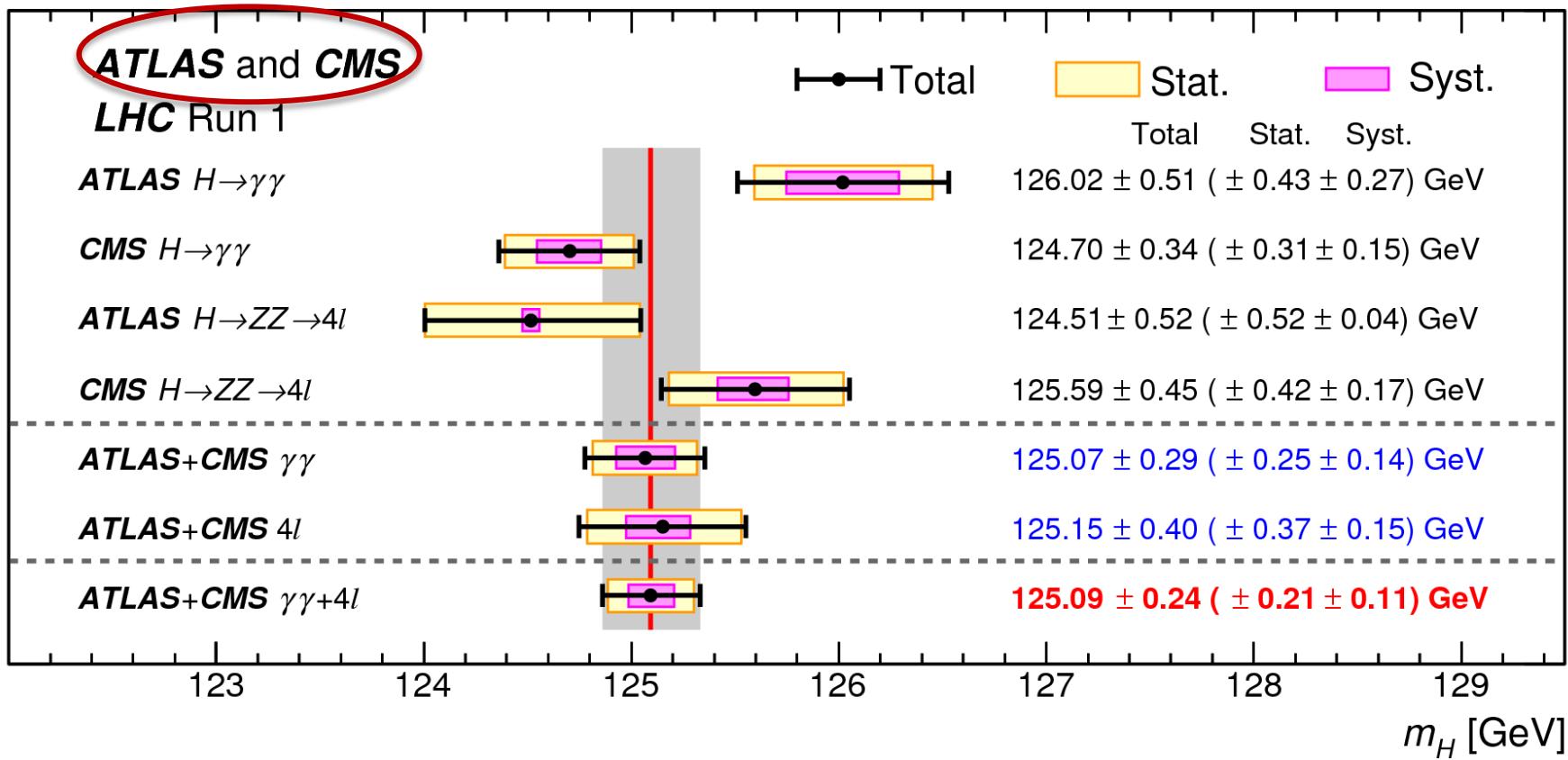
July 2012: Observation of a new boson





# The Higgs-Boson

NEW  
Mar.15



0.2% precision !

arXiv:1503.07589v1



# Higgs Properties

Mass:  $125.09 \pm 0.24 \text{ GeV}$

5 measured decays  
couplings (see plot)

Spin<sup>P</sup>:  $0^+$

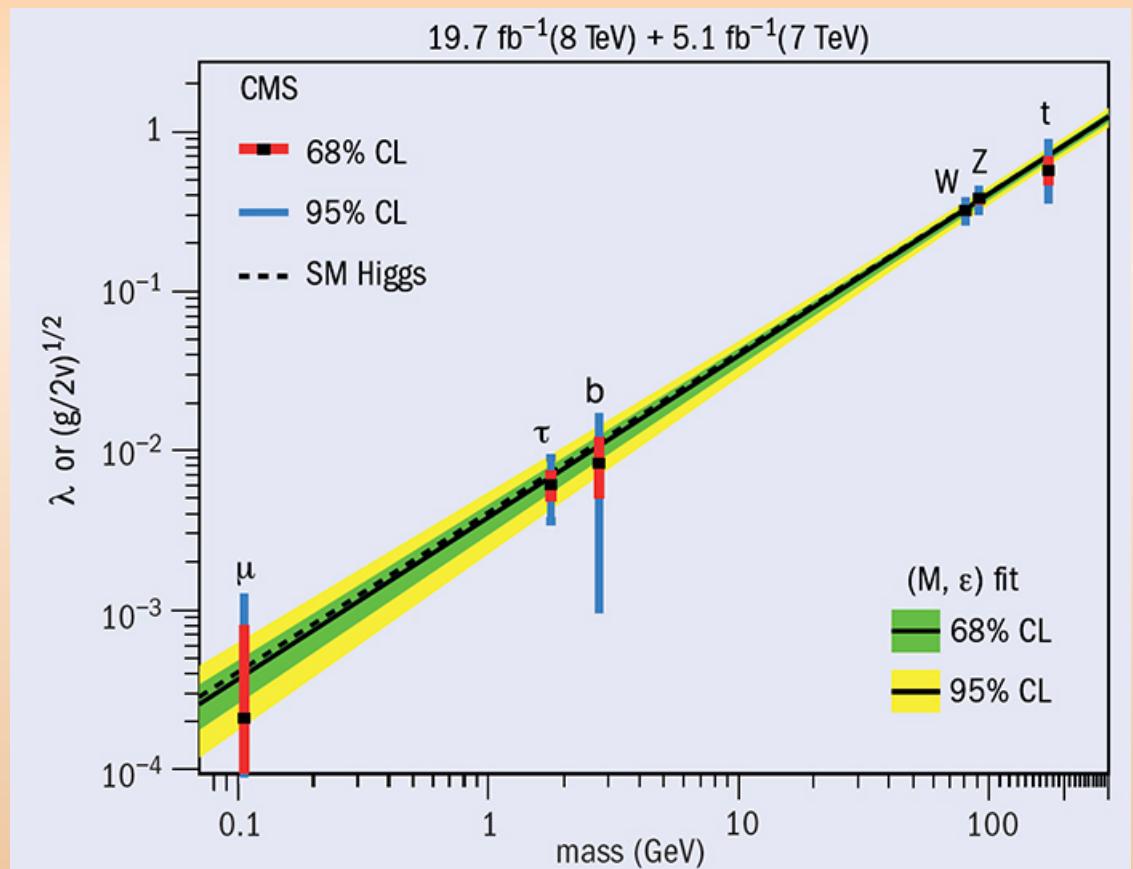
CP-Parity: + favoured,  
pure – excluded

Width:  $\Gamma_H < 4 \Gamma_{SM}$

Limits on  $H \rightarrow \tau\mu$

Limits on FCNC ( $t \rightarrow qH$ )

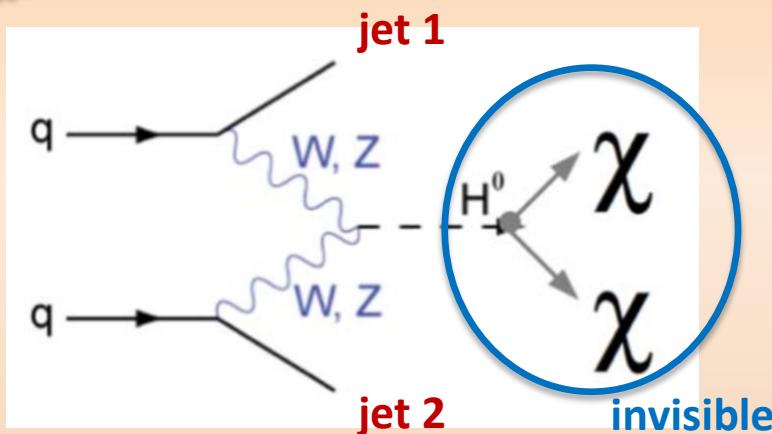
Limits on invisible decays





# Invisible Higgs-Decays

NEW  
Mar.'15



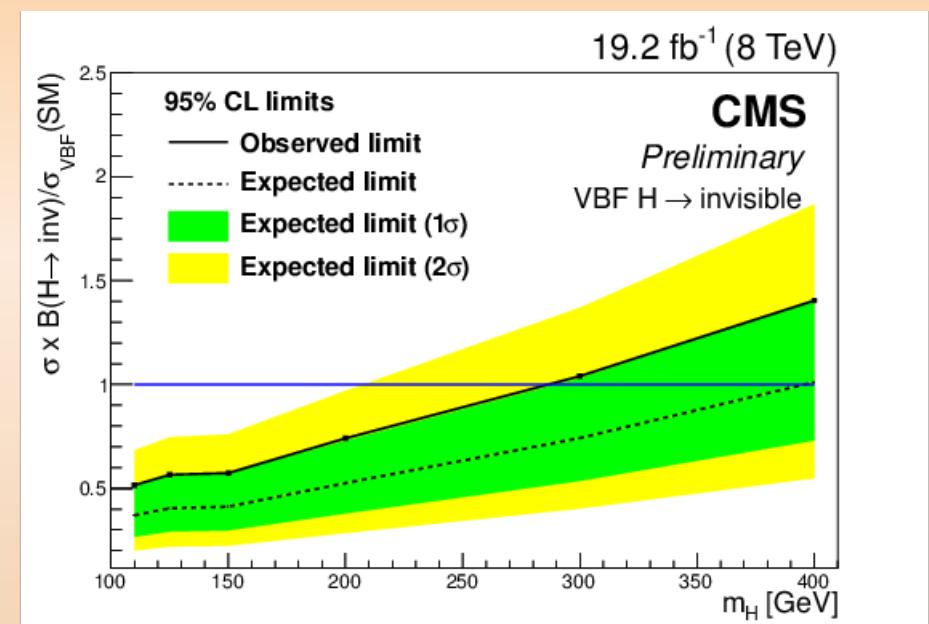
Selection through jet-kinematics:

$$\eta_j, \Delta\eta_{jj}, p_T(j), M_{jj}$$

$$E_T^{miss}, \Delta\phi(E_T^{miss}, j)$$

Parked trigger:

di-jet:  $p_T > 35(30) \text{ GeV}$ , VBF-tag



$$\mathcal{B}(H \rightarrow \text{inv.}) < 57\% \text{ (40\% exp.)}$$

combined with ZH

$$\mathcal{B}(H \rightarrow \text{inv.}) < 47\% \text{ (35\% exp.)}$$

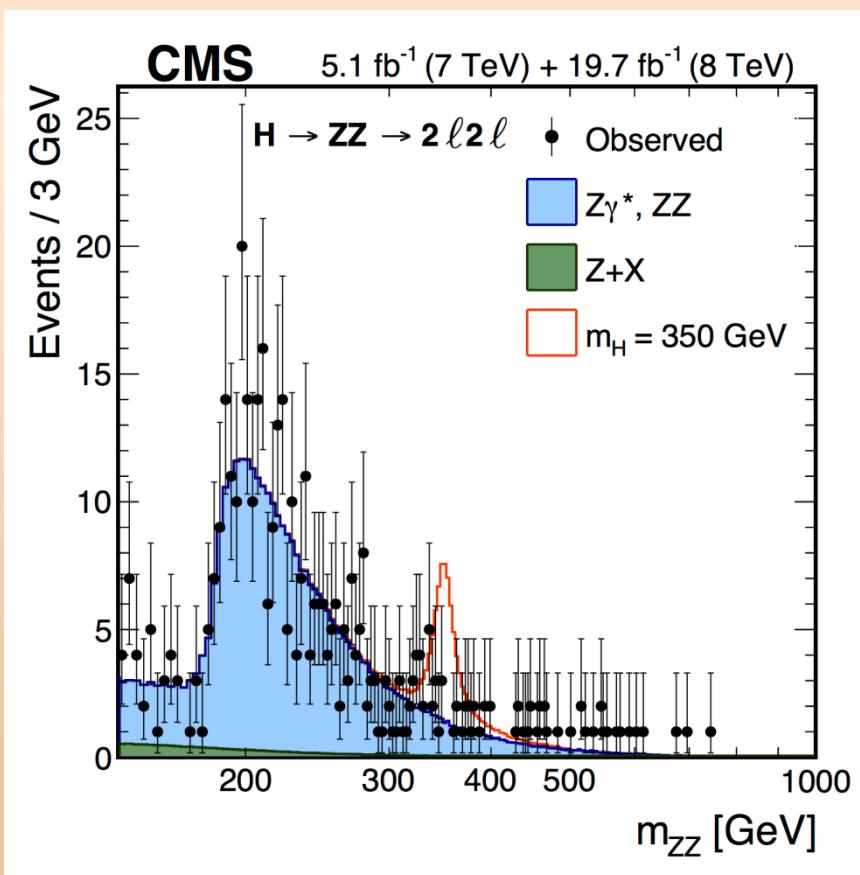
CMS-PAS-HIG-14-038



# More Higgs?

Many models predict more than 1 Higgs-Boson: Do we see any signs?

Searches in many channels



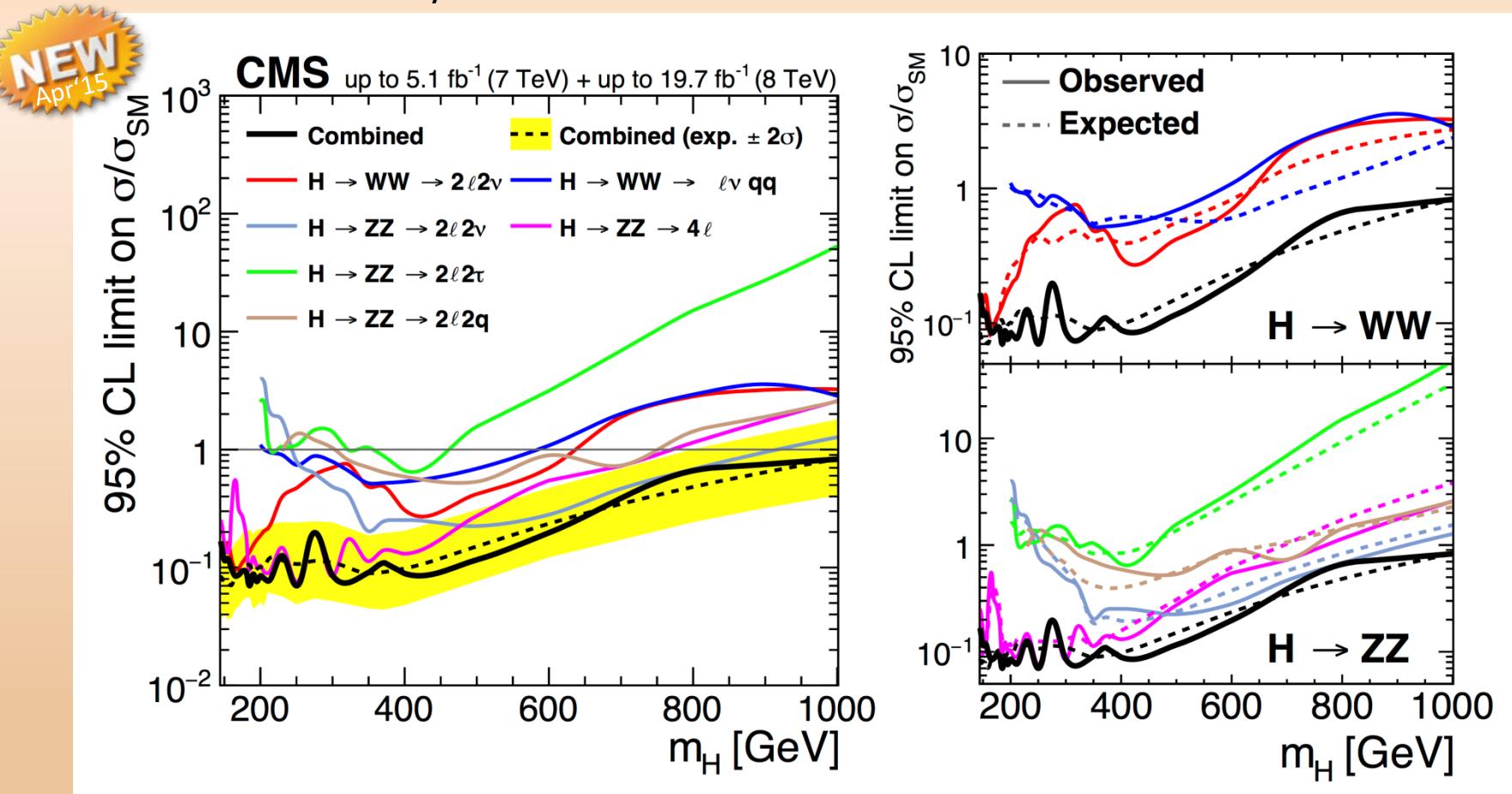
arXiv:1504.00936v1



# More Higgs?

Many models predict more than 1 Higgs-Boson: Do we see any signs?

Searches in many channels



world  
average

# Electroweak Fit

3 parameters define the e.w. part of the S.M.:

$$\nu, g, g'$$

for example:

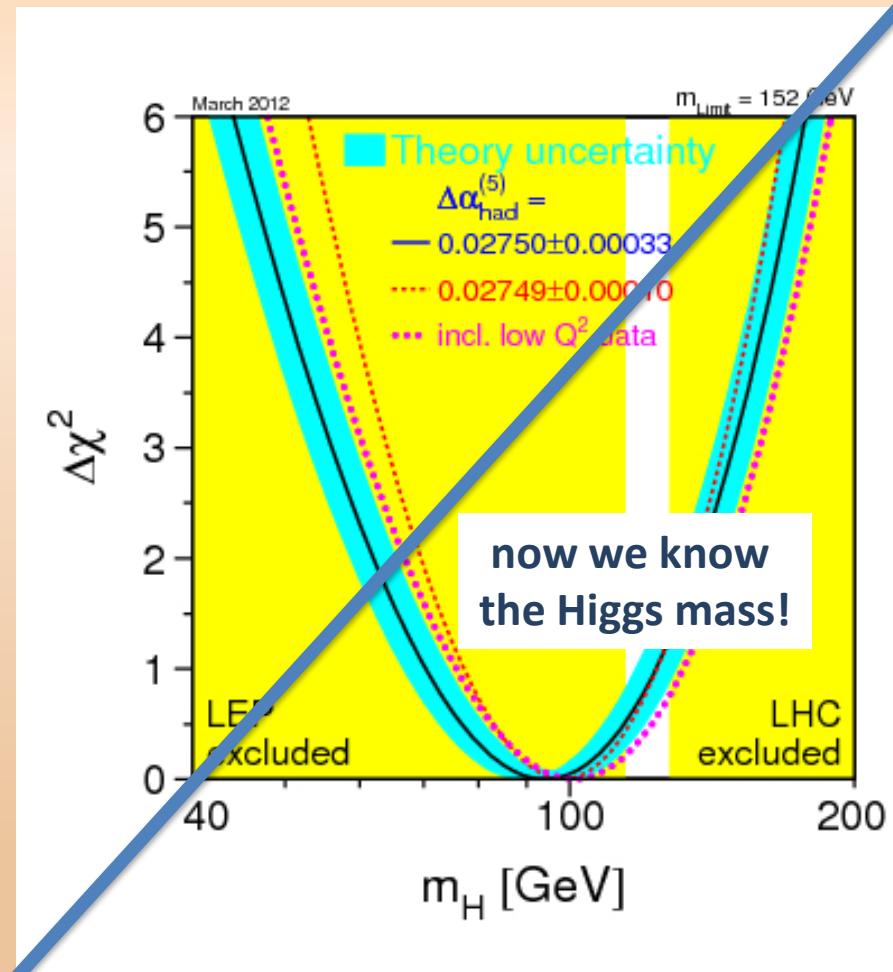
$$M_W = \frac{\nu |g|}{2}$$

$$M_Z = \frac{\nu \sqrt{g^2 + g'^2}}{2}$$

$$\cos \theta_W = \frac{|g|}{\sqrt{g^2 + g'^2}}$$

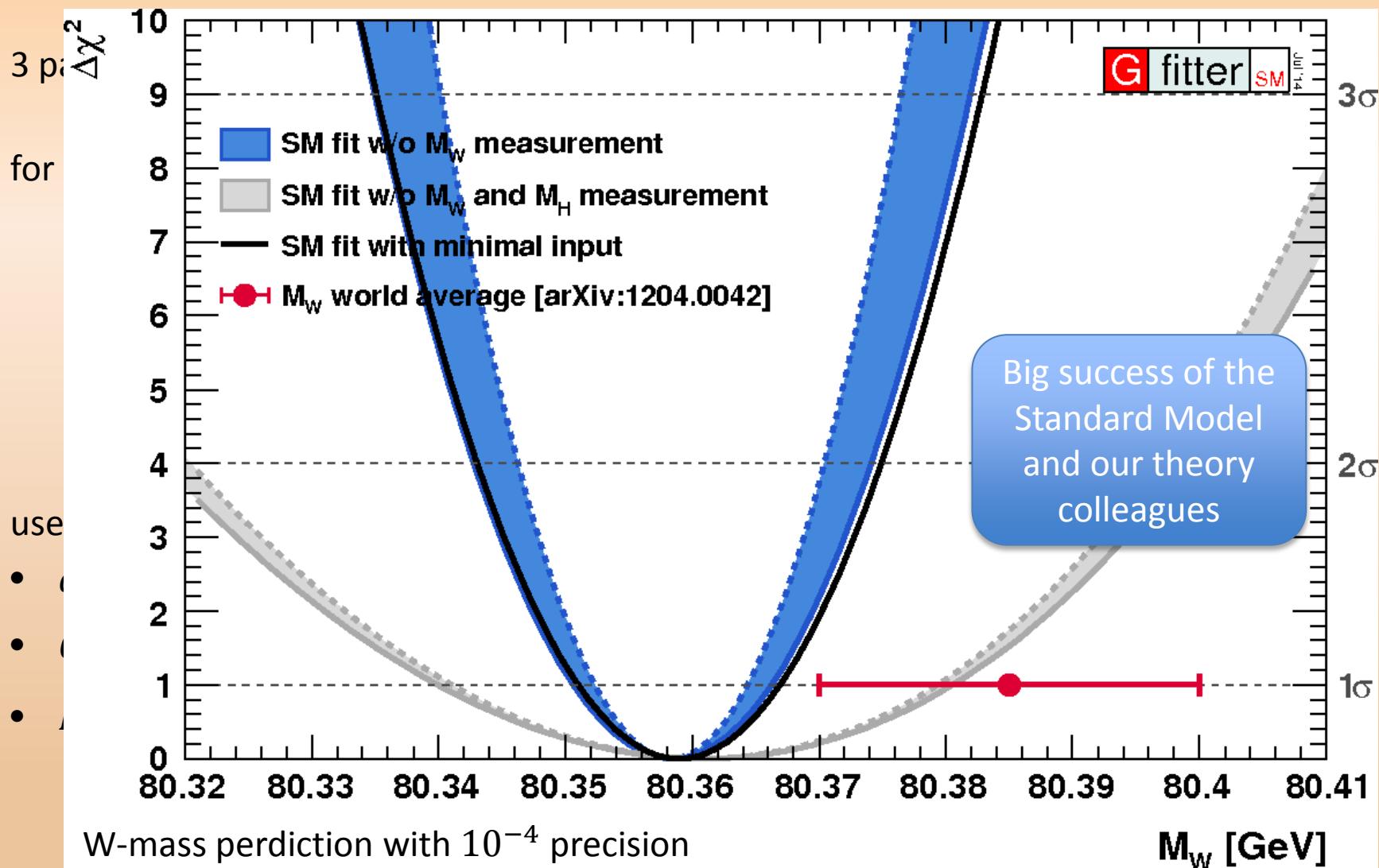
use most precise measurements

- $\alpha$  (Lamb-shift:  $\frac{\Delta \alpha}{\alpha} = 3 \cdot 10^{-10}$ )
- $G_F$  (muon lifetime:  $\frac{\Delta G_F}{G_F} = 5 \cdot 10^{-7}$ )
- $M_Z$  (LEP line shape:  $\frac{\Delta M_Z}{M_Z} = 2 \cdot 10^{-5}$ )



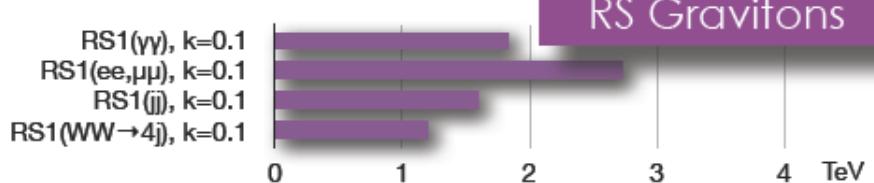
world  
average

# Electroweak Fit

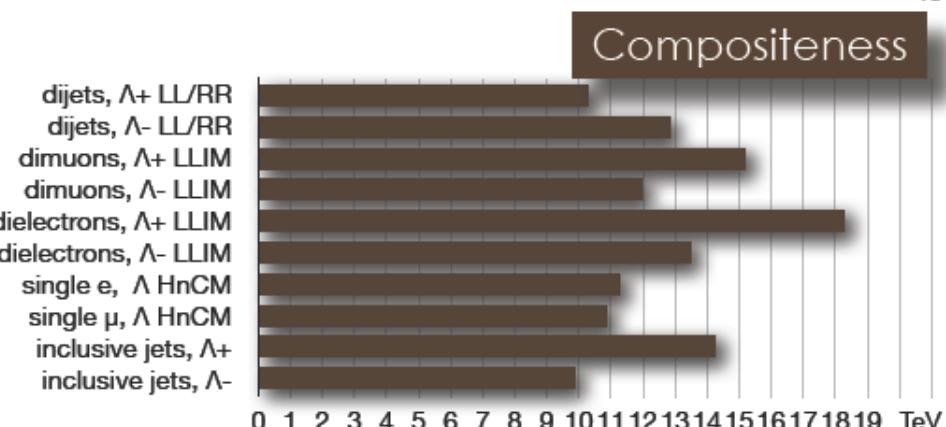
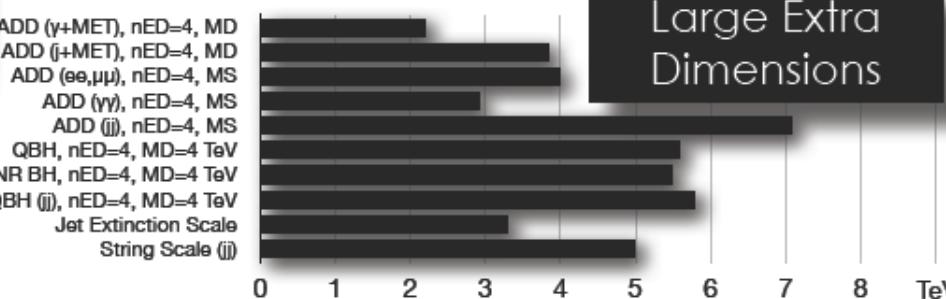
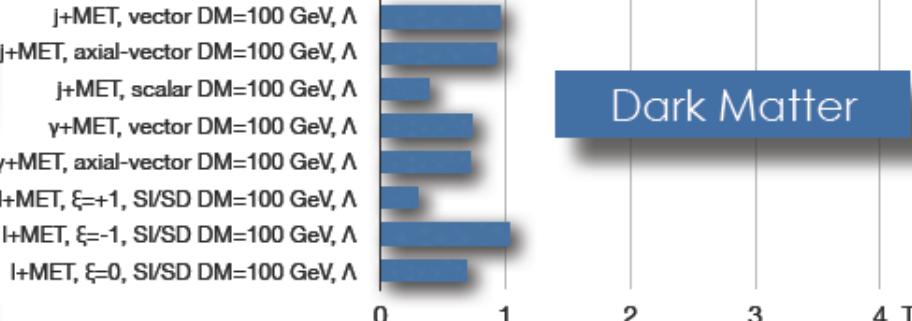
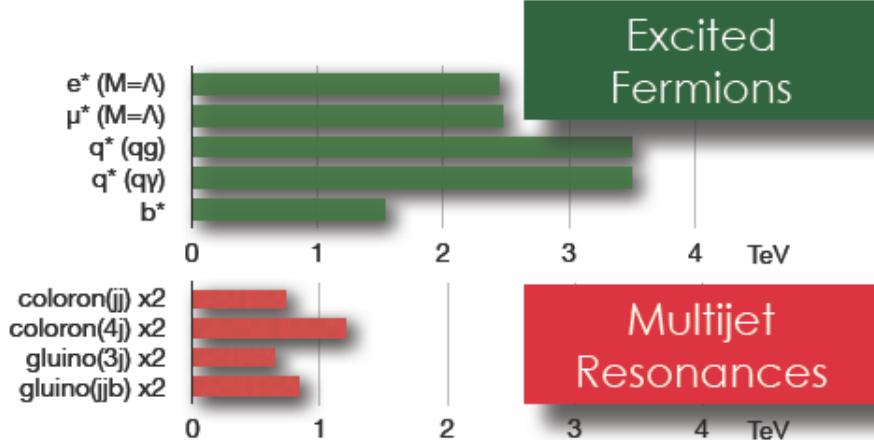
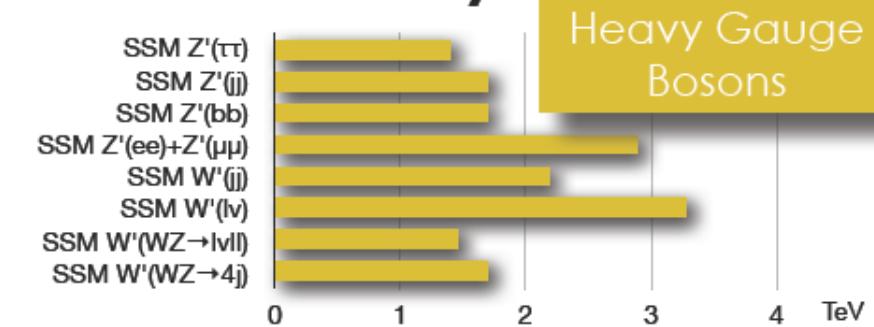




# BSM-Searches

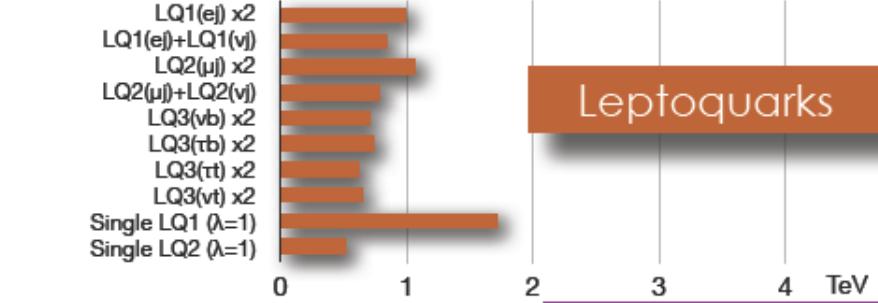


CMS Preliminary

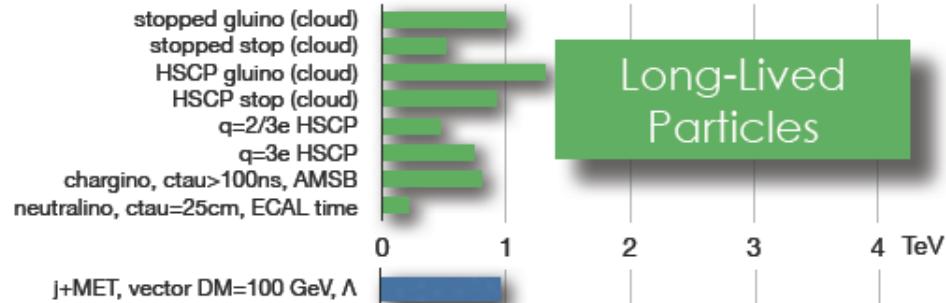


# CMS Prelim

RS1( $\gamma\gamma$ ),  $k=0.1$   
 RS1( $ee, \mu\mu$ ),  $k=0.1$   
 RS1( $jj$ ),  $k=0.1$   
 RS1( $WW \rightarrow 4j$ ),  $k=0.1$

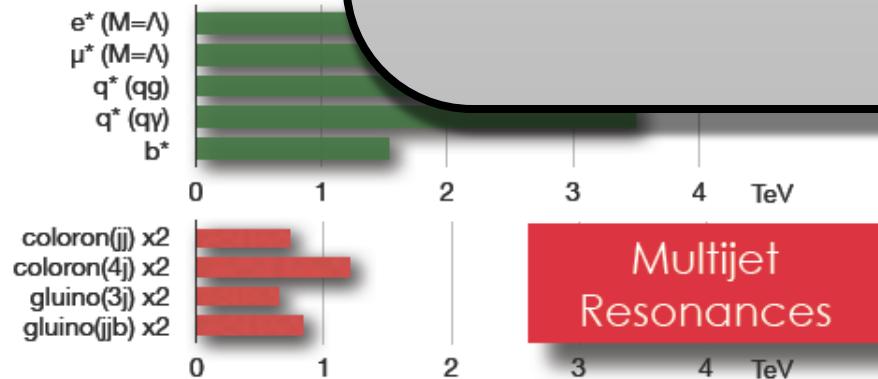


## Leptoquarks

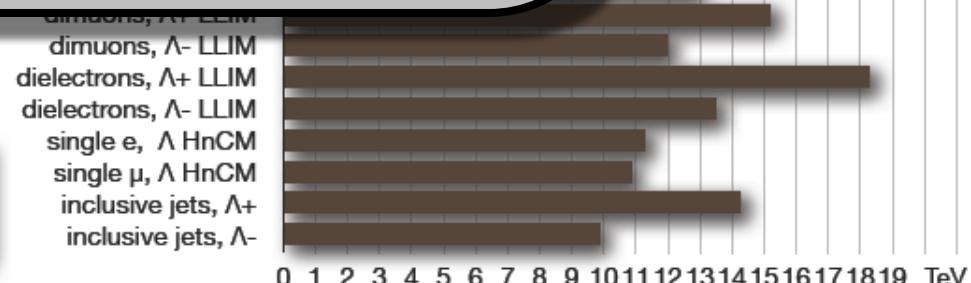


## Long-Lived Particles

SSM  $Z'(\pi\pi)$   
 SSM  $Z'(\gamma\gamma)$   
 SSM  $Z'(\text{bb})$   
 SSM  $Z'(\text{ee})+Z'(\mu\mu)$   
 SSM  $W'(\gamma\gamma)$   
 SSM  $W'(\text{lv})$   
 SSM  $W'(\text{WZ} \rightarrow \text{l}\nu\text{l}\nu)$   
 SSM  $W'(\text{WZ} \rightarrow 4j)$

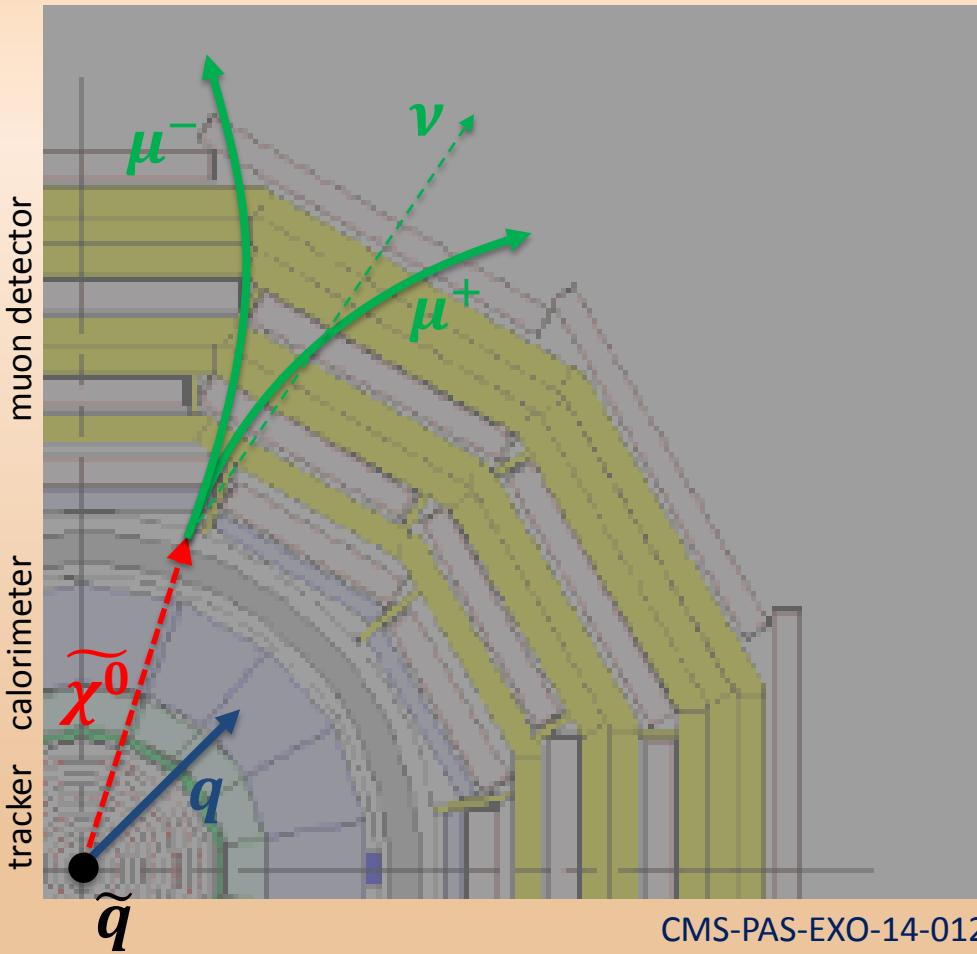


## Multi-jet Resonances



# Longlived Neutralinos

Search for longlived particles that decay into a pair of muons.



Two Analysis:

- tracks from the tracker
- tracks from the muon detector



potential model interpretation:

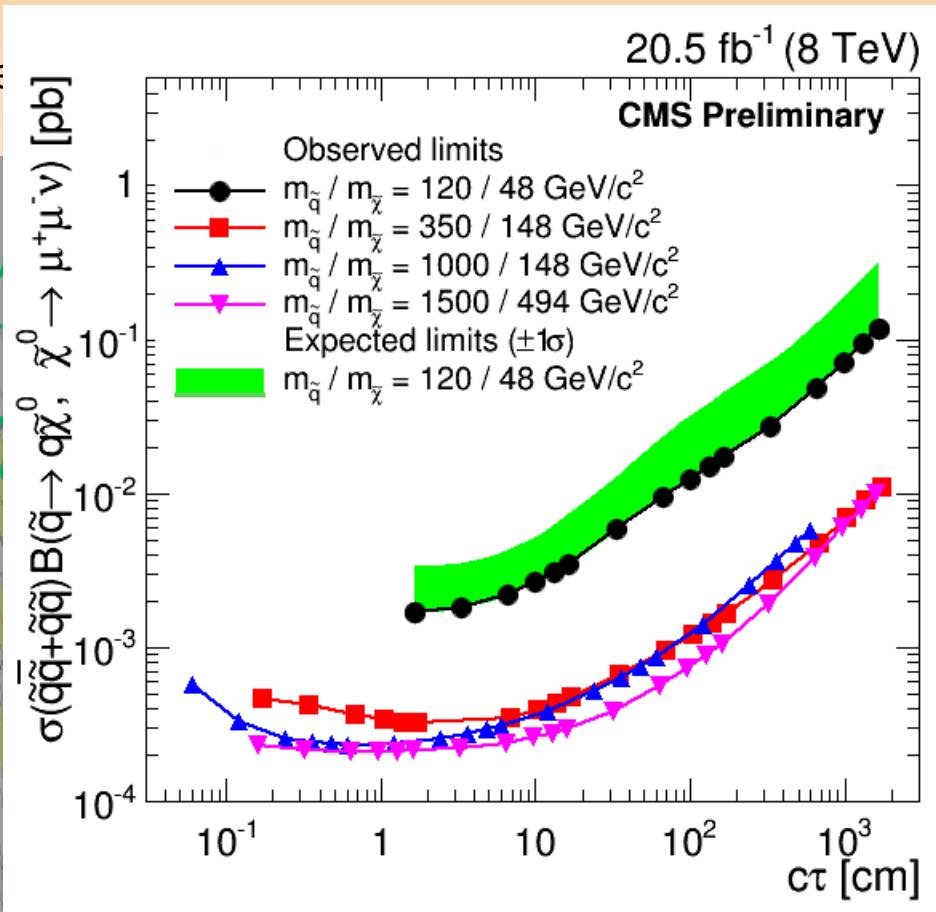
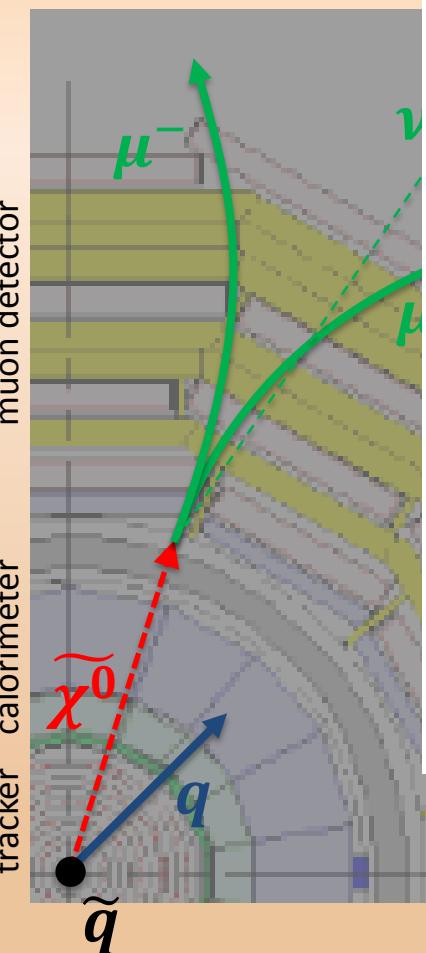
$$\begin{aligned} pp &\rightarrow \tilde{q}\tilde{q} \\ \tilde{q} &\rightarrow \widetilde{\chi^0} q \\ \widetilde{\chi^0} &\rightarrow \mu^+ \mu^- \nu \end{aligned}$$

No events found!



# Longlived Neutralinos

Search for longlived

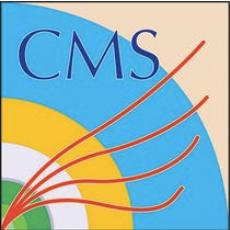


: the tracker  
: the myon detector  
**NEW Apr'15**

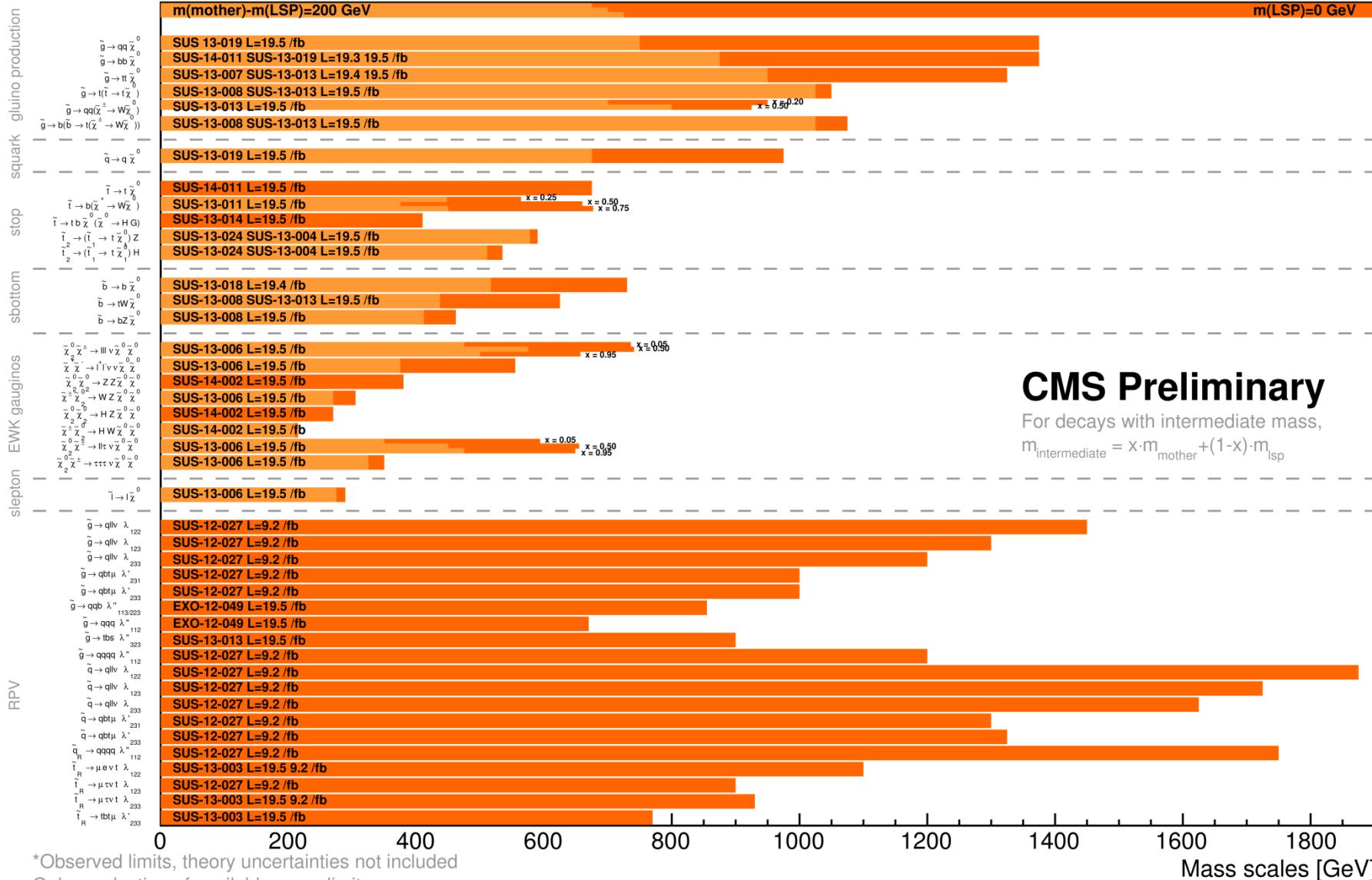
Model interpretation:

•  $\tilde{\chi}^0 q$   
 $\tilde{\chi}^0 \rightarrow \mu^+ \mu^- \nu$

Events found!

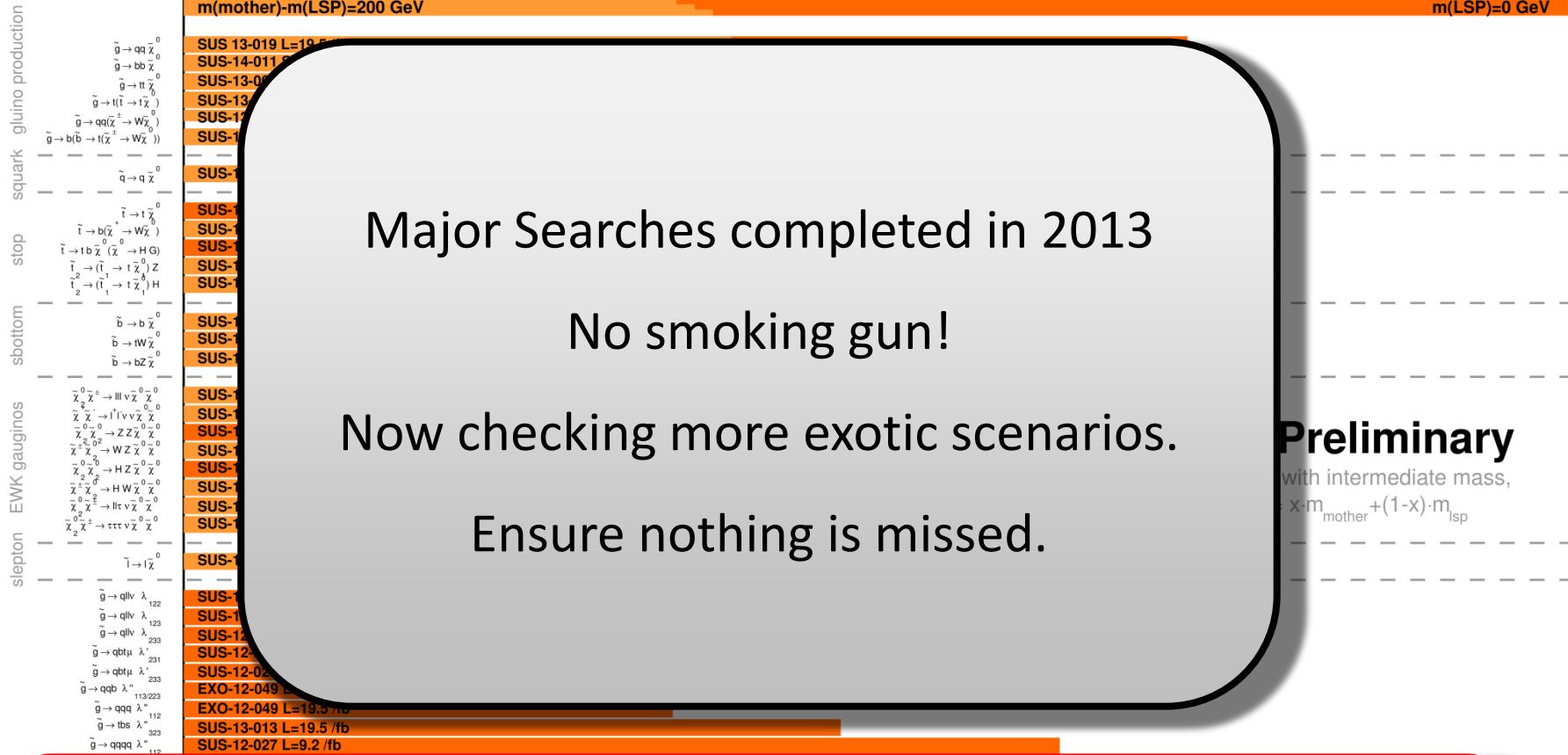


# SUSY-Searches





# SUSY-Searches



**But**

**we only collected 1% of the LHC Luminosity @ half the center-of-mass energy**

Observed limits, theory uncertainties not included

Only a selection of available mass limits

Probe \*up to\* the quoted mass limit

Mass scales [GeV]

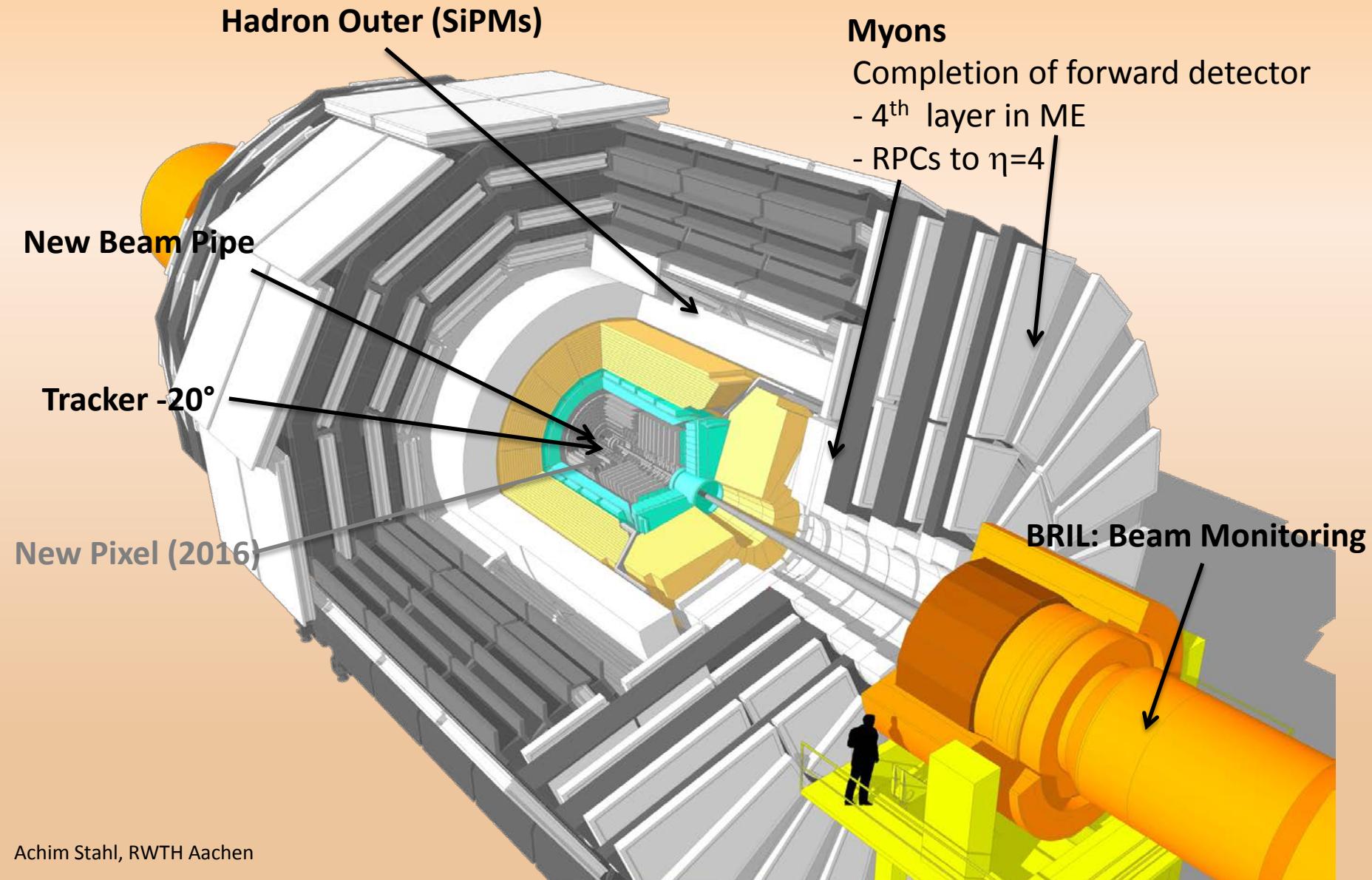


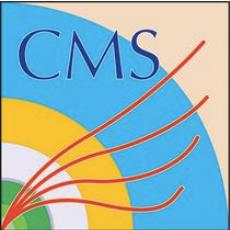
# Long Shutdown I



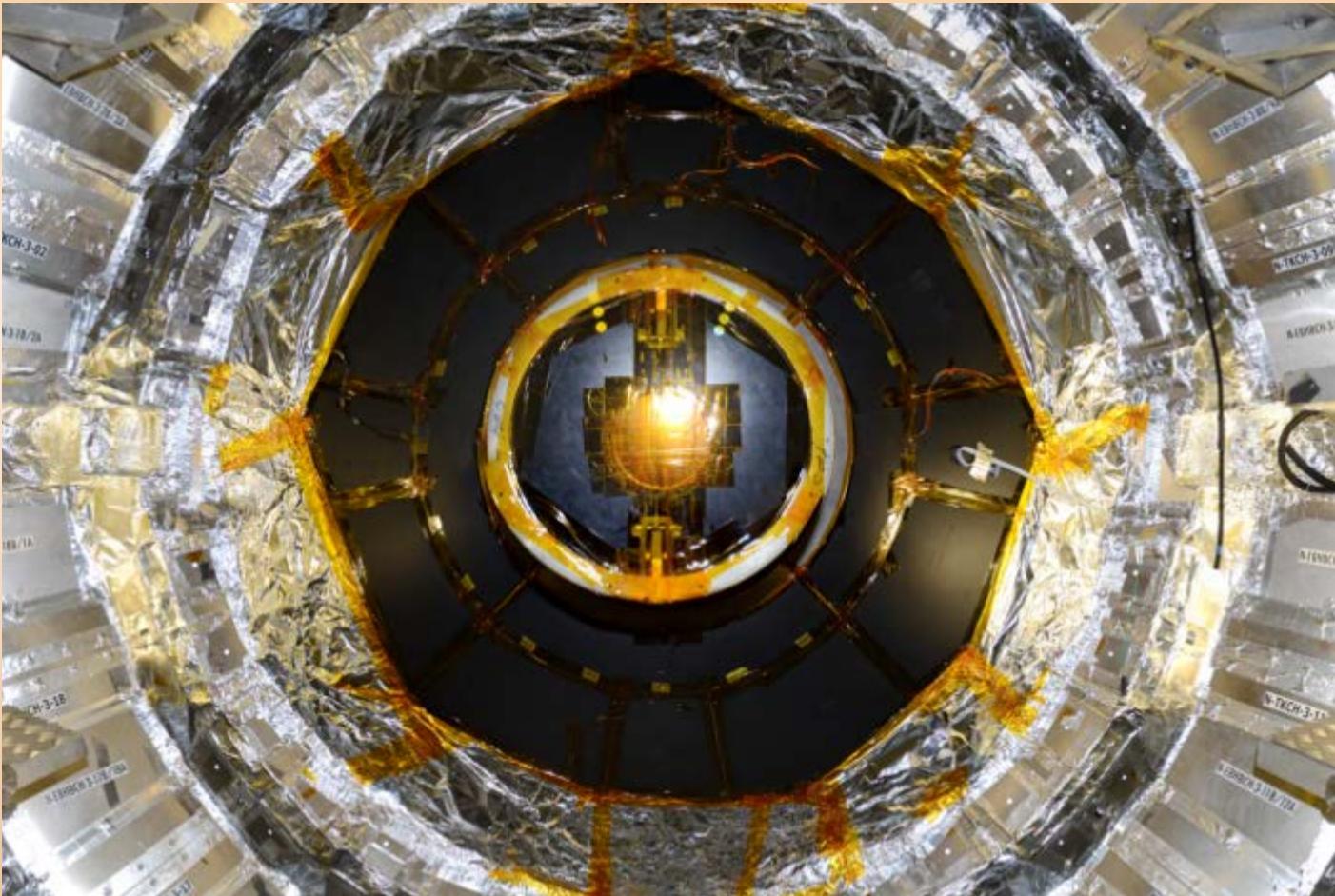


# LS1 - Overview

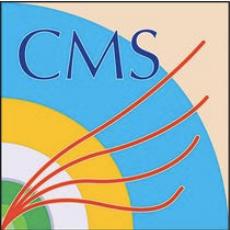




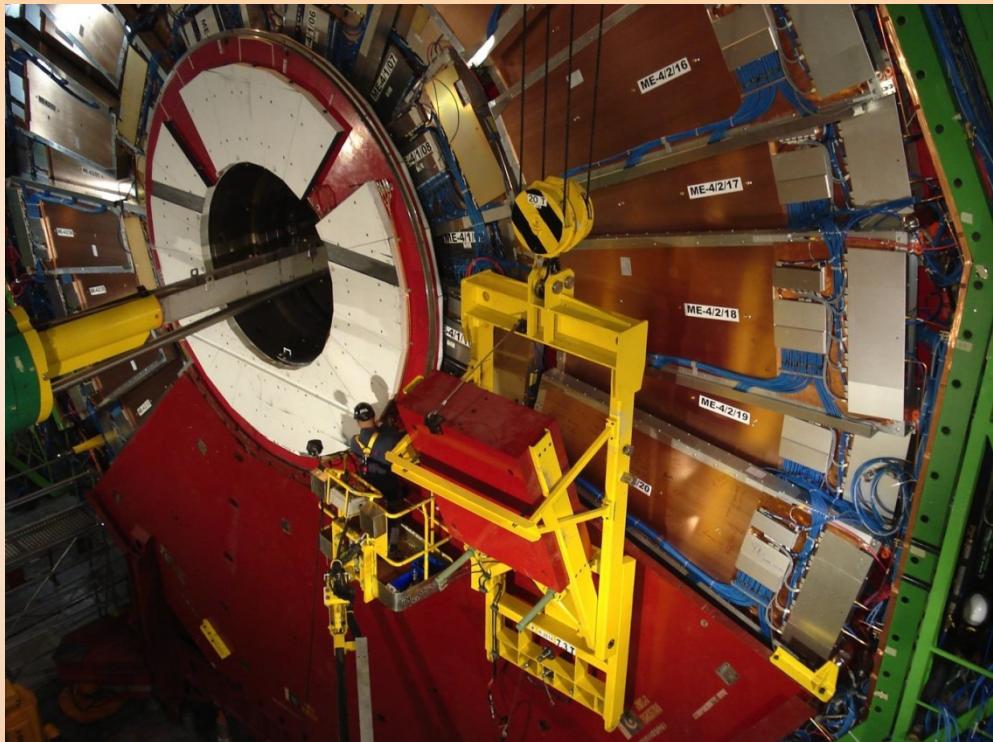
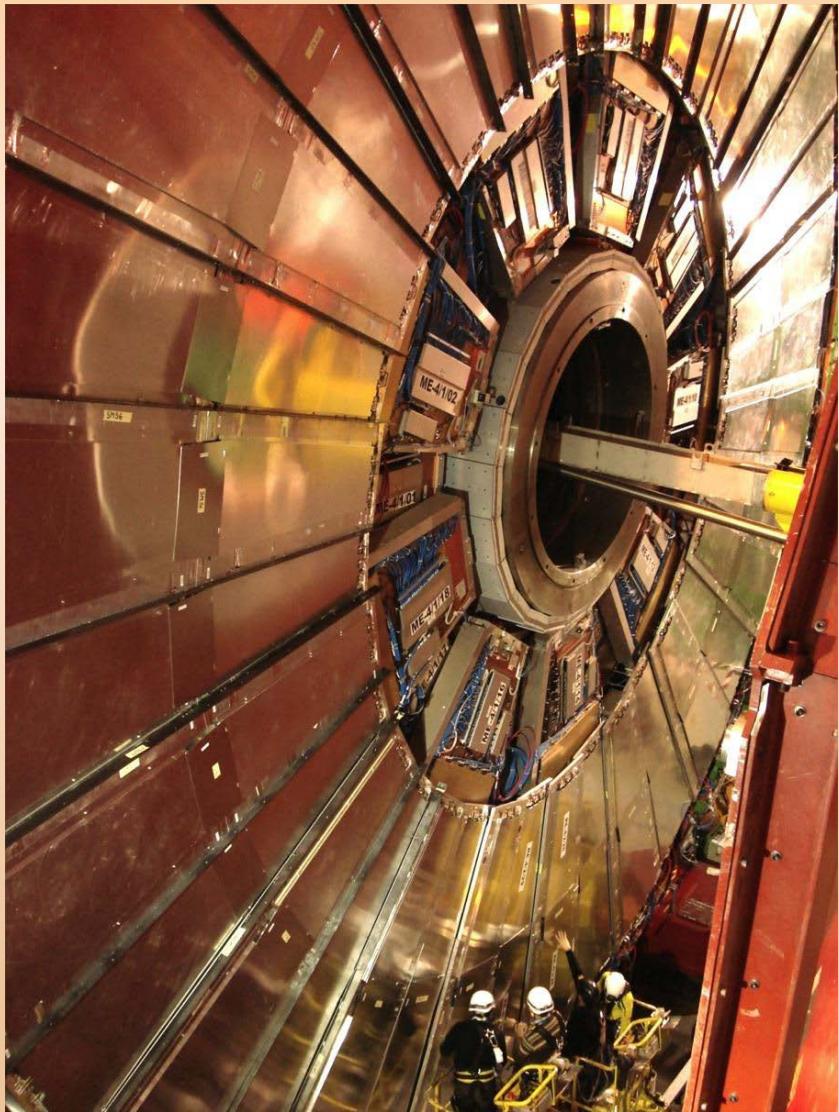
# Tracker Cooling



tracker must be operated at low temperature to reduce impact of radiation  
cooling capacity upgraded – environmental insulation improved



# Myon Endcaps: 4<sup>th</sup> layer



CMS designed with 4 layers of myon detectors  
Barrel: complete  
Endcap: 4<sup>th</sup> layer missing, completed in LS1



# New Beam Pipe

New beam pipe (OD 58mm → 45mm)  
In preparation of new pixel detector

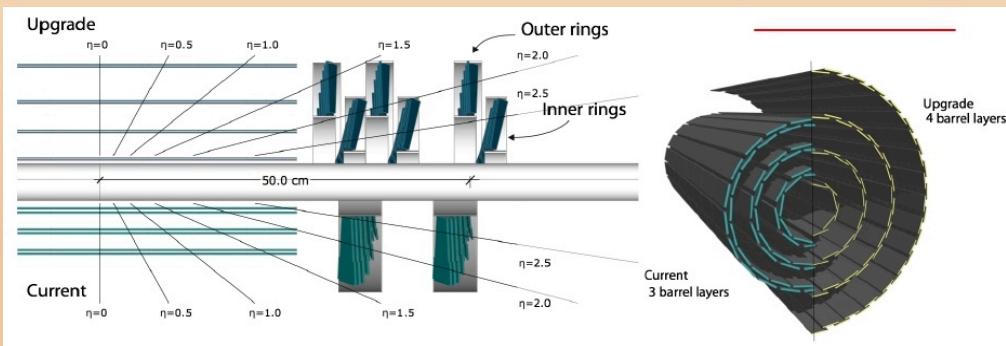


photo by Michael.Hoch@cern.ch

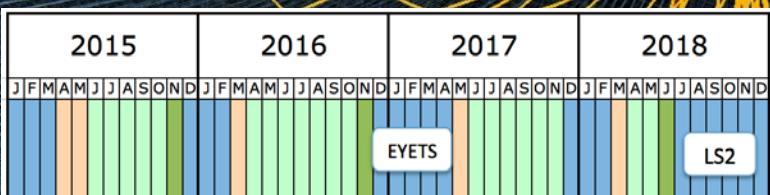


# Ready for Run II !

CMS Experiment at the LHC, CERN

Data recorded: 2010-Jul-09 02:25:58.839811 GMT(04:25:58 CEST)

Run / Event: 139779 / 4994190



Shutdown/Technical stop  
Protons physics  
Commissioning  
Ions



# Run 2

Waiting for surprises



# Outlook – HL-LHC

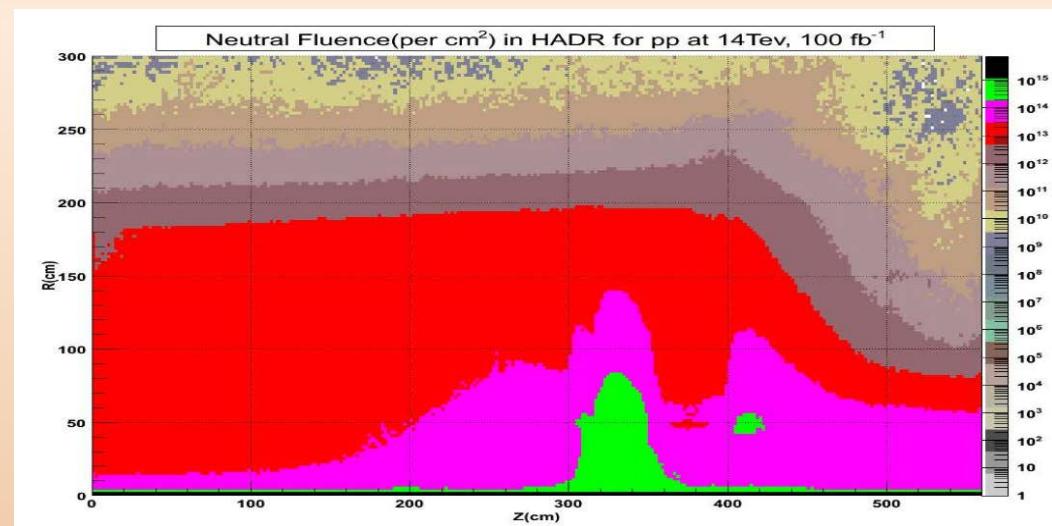
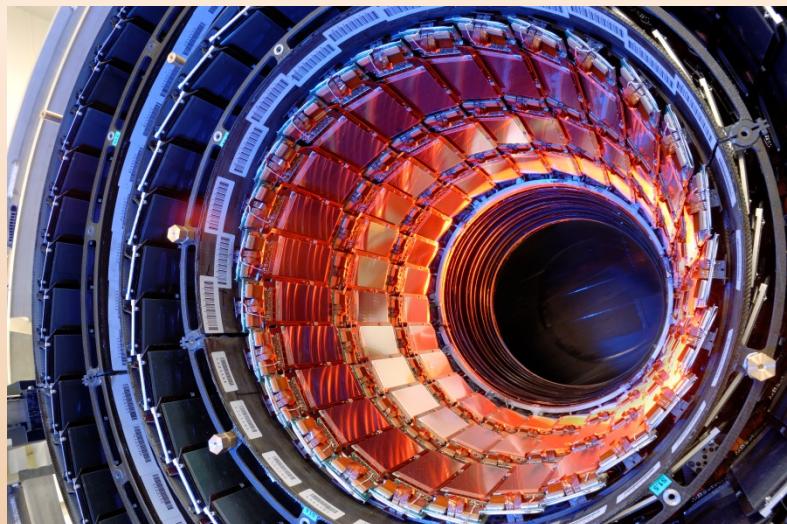
2010				2011				2012				2013				2014				2015				2016				2017				2018				2019			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4				
Run 1 7-8 TeV, $0.7 \times 10^{34}$ ( $\mu \approx 20$ ), $25 \text{ fb}^{-1}$								LS1								Run 2 13-14 TeV, $1.6 \times 10^{34}$ ( $\mu \approx 43$ ), $150 \text{ fb}^{-1}$								LS2 Phase-I Install															
2020				2021				2022				2023				2024				2025				2026				2027				2028				2029			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4				
Run 3 $14 \text{ TeV}, 2-3 \times 10^{34}$ ( $\mu \approx 50-80$ ), $350 \text{ fb}^{-1}$								LS3 – Phase-II Install								Run 4 $14 \text{ TeV}, 5-7 \times 10^{34}$ ( $\mu \approx 140-200$ ), $3000 \text{ fb}^{-1}$								LS4															



# High-Lumi LHC

Upgrade of the LHC implies a CMS detector upgrade

- improved triggers and electronics to cope with higher rates
- replacement of detector components at the end of their lifetime



Goal: Same performance as today in a much harsher environment.

R&D in progress



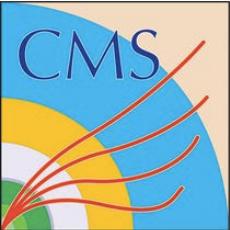
# Conclusions

- Many interesting results from RUN 1
- Consolidation of detector during LS1
- Ready for Run 2

Stay tuned!



# Backup



# LHC schedule

towards first collisions ...

Apr		May										June				
Wk	Mo	14	15	16	17	18	19	20	21	22	23	24	25	26		
Mo		30	Easter Mon	6	13	20	27	4	11	18	Whit	25	1	8	15	22
Tu																
We			Injector TS		Recommissioning with beam						Special physic run	TS1				
Th								Ascension								
Fr		G. Friday				1st May										
Sa				today												
Su																

Scrubbing for 50 ns  
operation



Intensity ramp-up  
with 50 ns beam

Scrubbing for 50 ns operation

	Apr	May	June												
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26		
Mo	30	Easter Mon	6	13	20	27	4	11	18	Whit	25	1	8	15	22
Tu															
We		Injector TS		Recommissioning with beam						TS1					
Th								Ascension							
Fr	G. Friday				1st May								Intensity ramp-up with 50 ns beam		
Sa															
Su															

Scrubbing for 25 ns operation

	July	Aug	Sep											
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39	
Mo	29	6	13	20	27	3	10	17	24	31	7	14	21	
Tu														
We	1			MD 1					TS2	MD 2				
Th					Intensity ramp-up with 25 ns beam						Jeune G			
Fr														
Sa					1						lower beta*			
Su														

End physics  
(16:00)

	Oct	Nov	Dec										
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	28	5	12	19	26	2	9	16	23	30	7	14	21
Tu													
We						TS3		Ions setup				Technical stop	
Th					MD 3					IONS			Xmas
Fr													
Sa													
Su													

Technical Stop

Machine development

Recommissioning with beam

Special physics runs (indicative - schedule to be established)

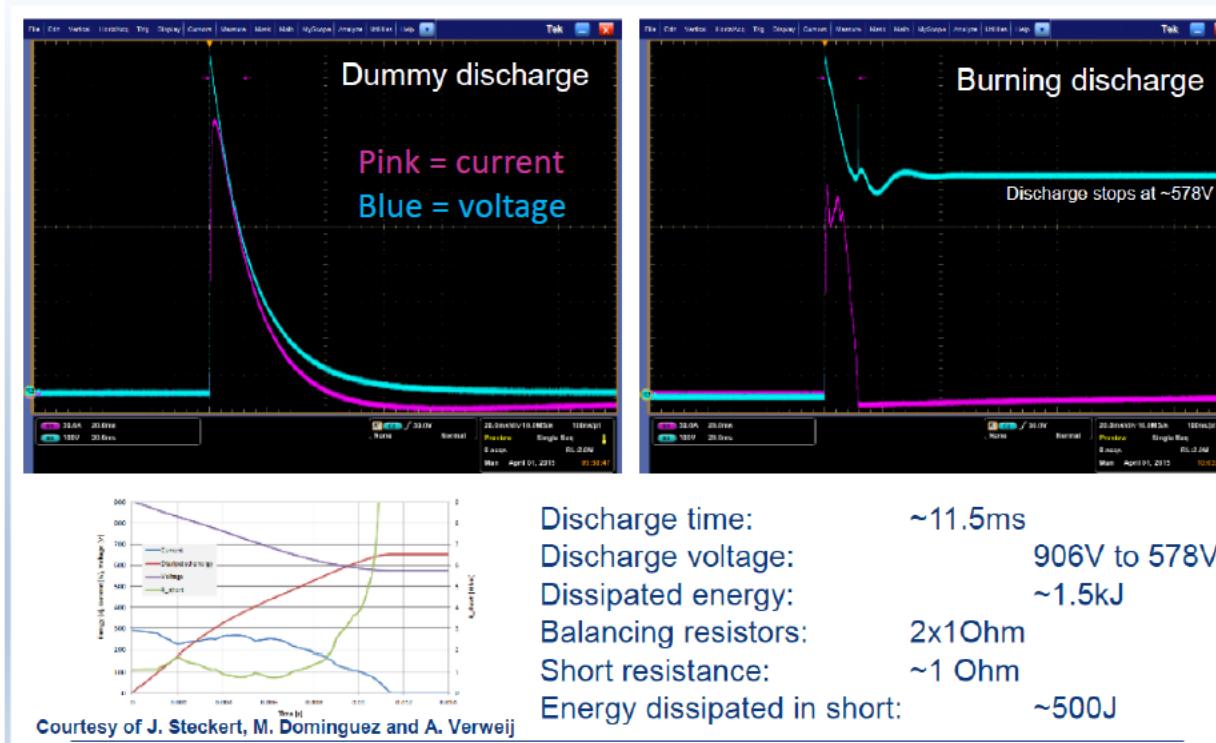
Scrubbing (indicative - dates to be established)

## Sector 34 ground short: solved

- Recall: intermittent ground short found during final training quench of sector 34
  - Located in diode box (in cold mass)
- After intense investigation by experts: decision to vaporize/burn the debris by capacitive discharge through the short
  - Next page →



# Zap!



From talk by A. Siemko at LMC 1 April 2015 (<https://indico.cern.ch/event/384311/>)