# Latest results from the LHC

Lucia Masetti Johannes Gutenberg University Mainz PRISMA Cluster of Excellence

#### LATTICE 2013 Mainz August 2<sup>nd</sup>, 2013





### LHC and its experiments

### The Large Hadron Collider





L. Masetti - 02/08/13

3



## LHC performance

	2011	2012	Nominal
Energy per beam (TeV)	3.5	4	7
Bunch spacing (ns)	50	50	25
Number of bunches	1380	1380	2808
Max intensity (protons/bunch)	1.45 x 10 <sup>11</sup>	1.7 x 10 <sup>11</sup>	1.15 x 10 <sup>11</sup>
Peak luminosity (cm <sup>-2</sup> s <sup>-1</sup> )	<b>3.7</b> x 10 <sup>33</sup>	7.7 x 10 <sup>33</sup>	1.0 x 10 <sup>34</sup>



4



## ATLAS, CMS and LHCb

	ATLAS	CMS CMS	LHCb Control of the second sec
Size	42 m x 22 m	22 m x 15 m	20 m x 13 m
Weight	7000 ton	12500 ton	5600 ton
Coverage	η <5	η <5	<b>2</b> <η<5
Vertex resolution	15 µm	15 µm	<b>7</b> μm
EM calo energy res.	1.2% @ 100 GeV	0.4% @ 100 GeV	1.4% @ 100 GeV
Hadron calo energy res.	6% @ 100 GeV	11% @ 100 GeV	11% @ 100 GeV
Muon momentum res.	10% @ 1 TeV	5% @ 1 TeV	0.6% @ 100 GeV
Particle ID	e/π		e/π/K/p





## Luminosity and pile-up







L. Masetti - 02/08/13

6



#### Latest results...

- ... since Moriond 2013:
- ATLAS: 19 papers, 47 preliminary results
- <u>CMS:</u> 24 papers, 69 preliminary results
- LHCb: 33 papers, 9 preliminary results
- Only a very personal selection of these results will be presented here



L. Masetti - 02/08/13





#### Direct CPV in charm?

9

#### Search for direct CPV in D<sup>0</sup>→h<sup>+</sup>h<sup>-</sup> LHCb: 1/fb @ 7 TeV Phys. Lett. B 723 (2013) 33 D<sup>0</sup>'s from semileptonic B decays µ charge used to tag D<sup>0</sup> and D<sup>0</sup> Muon detection and effective production asymmetries cancel in the difference between KK and ππ

$$\Delta A_{CP} \approx \Delta a_{CP}^{\text{dir}} \left( 1 + y \frac{\overline{\langle t \rangle}}{\tau} \cos \phi \right) + \left( a_{CP}^{\text{ind}} + \overline{a_{CP}^{\text{dir}}} y \cos \phi \right) \frac{\Delta \langle t \rangle}{\tau} \approx \Delta a_{CP}^{\text{dir}}$$

 $\Delta A_{CP} = (0.49 \pm 0.30 \,(\text{stat}) \pm 0.14 \,(\text{syst}))\%$ 

L. Masetti - 02/08/13

Cluster of Excellence



### Direct CPV in Bs

#### Direct CPV in B<sub>s</sub><sup>0</sup>→K<sup>-</sup>π<sup>+</sup> LHCb: 1/fb @ 7 TeV PRL 110 (2013) 221601

Raw asymmetry corrected for instrumental and production effects using D<sup>0</sup> and Lambda decays and time dependent asymmetry **FIRST OBSERVATION** 



 $A_{CP}(B^0 \to K^+ \pi^-) = -0.080 \pm 0.007 \,(\text{stat}) \pm 0.003 \,(\text{syst})$  $A_{CP}(B^0_s \to K^- \pi^+) = 0.27 \pm 0.04 \,(\text{stat}) \pm 0.01 \,(\text{syst})$  $A_{CP}(B^0_s \to K^+ \pi^-) = \mathcal{R}(B^0 \to K^- \pi^+) \,\pi + \text{Holdinkin}$ 

 $\Delta = \frac{A_{CP}(B^0 \to K^+ \pi^-)}{A_{CP}(B^0_s \to K^- \pi^+)} + \frac{\mathcal{B}(B^0_s \to K^- \pi^+)}{\mathcal{B}(B^0 \to K^+ \pi^-)} \frac{\tau_d}{\tau_s} \quad \frac{\text{H.J. Lipkin}}{(2005)}$ 

10.5 σ: most precide measurement 6.5 σ: first observation

 $\Delta = -0.02 \pm 0.05 \pm 0.04$ Compatible with SM:  $\Delta = 0$ 





## B<sub>s</sub> mixing phase

CPV and  $\Delta \Gamma_s$  from  $B_s^0 \rightarrow J/\Psi K^+K^-$  and  $B_s^0 \rightarrow J/\Psi \pi^+ \pi^-$ LHCb: 1/fb @ 7 TeV Phys. Rev. D 87 (2013) 112010 Angular analysis in bins of m(K<sup>+</sup>K<sup>-</sup>) Update of  $B_s^0 \rightarrow J/\Psi \pi^+ \pi^-$  analysis Opposite side and same side tagging **MOST PRECISE measurements** of  $\Phi_s$ ,  $\Gamma_s$  and  $\Delta\Gamma_s$ ATLAS: 4.9/fb @ 7 TeV **ATLAS-CONF-2013-039** Angular analysis of  $B_s^0 \rightarrow J/\Psi K^+K^-$ **Opposite side tagging** 





Angles in the helicity basis





JOHANNES GUTENBERG UNIVERSITÄT MAINZ

## New observables in $b \rightarrow s \mu \mu$

Differential branching fraction and angular analysis of B<sup>0</sup>→K<sup>\*0</sup>µ<sup>+</sup>µ<sup>-</sup> LHCb: 1/fb @ 7 TeV <u>arXiv:1304.6325</u> ATLAS: 4.9/fb @ 7 TeV <u>ATLAS-CONF-2013-038</u> CMS: 5.2/fb @ 7 TeV <u>CMS PAS BPH-11-009</u> New observables presented at EPS LHCb: 1/fb @ 7 TeV LHCb-PAPER-037

Form factor independent parameters (<u>arXiv:1303.5794</u>) accessible via folding techniques **3.7 σ discrepancy in P'**<sub>5</sub> at low q<sup>2</sup>



All other measurements agree with SM prediction

12





30

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

## Top quark properties

## Production and properties









Charge asymmetry Spin correlations Top polarisation Resonances Vector-like quarks Stops

W polarisation Couplings (ttH, tty, ttZ) FCNC



L. Masetti - 02/08/13

15



## Single top production

Wt associated production CMS: 12/fb @ 8 TeV <u>CMS PAS TOP-12-040</u>

Multivariate analysis in the dilepton + jet channel **FIRST OBSERVATION**  $\sigma_{Wt} = 23.4^{+5.5}_{-5.4} \text{ pb}$ 

 $|V_{tb}| = 1.03 \pm 0.12(exp.) \pm 0.04(th.)$ 

#### ATLAS: 2/fb @ 7 TeV Phys. Lett. B 716 (2012) 142 EVIDENCE

 $\sigma_{Wt} = 16.8 \pm 2.9 \text{ (stat)} \pm 4.9 \text{ (syst) pb}$  $|V_{tb}| = 1.03^{+0.16}_{-0.19}$ 



L. Masetti - 02/08/13



#### Direct mass measurement



Latest measurements ATLAS: 4.7/fb @ 7 TeV ATLAS-CONF-2013-046 3D template fit in lepton+jets channel ATLAS: 4.7/fb @ 7 TeV **ATLAS-CONF-2013-077** Template fit in dilepton channel CMS: 3.5/fb @ 7 TeV arXiv:1307.4617 Ideogram method in all-jet channel LHC not yet as precise as Tevatron Work ongoing towards common treatment of systematics JGU Latest results from the LHC

> JOHANNES GUTENBERG UNIVERSITÄT MAINZ

#### Pole mass measurement



UNIVERSITÄT MAINZ

#### More mass measurements

#### Lifetime based measurement CMS: 19/fb @ 8 TeV **CMS PAS TOP-12-030**

 $m_{\rm t} = 173.5 \pm 1.5_{\rm stat} \pm 1.3_{\rm syst} \pm 2.6_{p_T({\rm t})} {\rm GeV}$ 

#### **Differential measurement** CMS: 5/fb @ 7 TeV CMS PAS TOP-12-029

Dependence on kinematic variables sensitive to color connection, initial and final state radiation

#### m<sub>r</sub>-m<sub>t</sub> CMS: 19/fb @ 8 TeV **CMS PAS TOP-12-031**



L. Masetti - 02/08/13

19

Latest results from the LHC

 $\Delta m_{\rm t} = -272 \pm 196 \, ({\rm stat.}) \pm 122 \, ({\rm syst.}) \, {\rm MeV}$ 







JOHANNES GUTENBERG UNIVERSITAT MAINZ

## Higgs boson properties

## Production and decay

All production and most decay processes are investigated at the LHC





UNIVERSITÄT MAINZ

### $H \rightarrow \gamma \gamma$ differential



#### $H \rightarrow ZZ$



Cluster of Excellence

JOHANNES GUTENBERG **UNIVERSITÄT** MAINZ

### 

#### Signal strength in H→WW\*→ℓℓvv ATLAS: 25/fb @ 7 and 8 TeV ATLAS: 25/fb @ 7 and 8 TeV arXiv:1307.1427

Transverse mass fit in 12 production and decay categories  $\frac{1}{8}$  $\mu = 0.99^{+0.31} - 0.28$ 

CMS: 25/fb @ 7 and 8 TeV CMS PAS HIG-13-003

2D template fit in 6 production and decay categories

 $\mu = 0.76 \pm 0.21$ 

L. Masetti - 02/08/13





Latest results from the LHC

200

300

100

JOHANNES GUTENBERG **UNIVERSITÄT** MAINZ

JGU

400 500 600

m<sub>н</sub> [GeV]





JOHANNES GUTENBERG **UNIVERSITAT** MAINZ

Cluster of Excellence



Signal strength in associated production with W or Z ATLAS: 25/fb @ 7 and 8 TeV <u>ATLAS-CONF-2013-079</u>

Mass fit in 26 event categories  $\mu = 0.2^{+0.7}$ -0.6

CMS: 25/fb @ 7 and 8 TeV <u>CMS PAS HIG-13-012</u> Fit of multivariate discriminant for different masses  $\mu = 1.0\pm0.5$ 



L. Masetti - 02/08/13



**UNIVERSITÄT** MAINZ

## Signal strength combination



UNIVERSITÄT MAINZ

## Couplings

#### Couplings to vector bosons and fermions from measured signal strengths in different production and decay channels



### Spin and parity

Spin and parity in  $H \rightarrow \gamma \gamma, H \rightarrow ZZ$  and  $H \rightarrow WW$ ATLAS: 20/fb @ 8 TeV <u>arXiv:1307.1432</u>

CMS: 20/fb @ 8 TeV <u>CMS PAS HIG-13-002</u> H→ZZ

CMS: 20/fb @ 8 TeV <u>CMS PAS HIG-13-016</u> H→γγ



L. Masetti - 02/08/13

Entries / 0.2 52 57

15

10

5

0

-1



JOHANNES GUTENBERG UNIVERSITÄT MAINZ



## Signature based searches

#### The ideal search:

- Covers many signatures
- is model
  independent
- + can be used to test future models

We searched... .... and we set limits on benchmark models





L. Masetti - 02/08/13

32

Latest results from the LHC

JGU JOHANNES GUTENBERG UNIVERSITÄT MAINZ

### Low mass dijet resonances

#### Dijet resonances associated with a vector boson ATLAS: 20/fb @ 8 TeV <u>ATLAS-CONF-2013-074</u>

ℓvjj and ℓℓjj topologies
 Background modelling checked in orthogonal control regions
 Template fit in the dijet mass distribution
 Limits on the ρ<sub>T</sub>→Vπ<sub>T</sub> cross section in the Low Scale TechniColor (LSCT) model
 CDF excess is excluded

 $m(\pi_{\rm T}) > 180 \text{ GeV} @ 95\% \text{ CL}$ 





JOHANNES GUTENBERG UNIVERSITÄT MAINZ

IGU

### Boosted W and Z

W/Z tagged dijet resonances CMS: 20/fb @ 8 TeV **CMS PAS EXO-12-024** Vector boson identification with jet substructure techniques Dark matter pair production with single W/Z tagged jets ATLAS: 20/fb @ 8 TeV ATLAS-CONF-2013-073 Single boosted vector boson with large missing transverse momentum World's strongest limit in a model with **up-down interference** 

Process	Observed Mass Exclusion(TeV)		
	8 TeV	7 TeV	
$q^* \rightarrow qW$	[1.00, 3.23]	[1.00, 2.38]	
$q^* \rightarrow qZ$	[1.00, 3.00]	[1.00, 2.15]	
$G_{RS} \rightarrow WW$	[1.00, 1.59]	NA	
$G_{RS} \rightarrow ZZ$	[1.00, 1.17]	NA	
$W' \rightarrow WZ$	[1.00, 1.73]	NA	







### Vector-like quarks

TT production with  $T \rightarrow bW$ , tZ and tH decays CMS: 20/fb @ 8 TeV CMS PAS B2G-12-015 Combined limits on T mass ATLAS: 14/fb @ 8 TeV ATLAS-CONF-2013-018 ATLAS-CONF-2013-051 ATLAS-CONF-2013-056 ATLAS-CONF-2013-060 Each analysis sensitive to one decay channel Limits superimposed



**UNIVERSITÄT** MAINZ



#### SUSY searches

#### Very strong limits on CMSSM

Moving on to Simplified Models and "Natural SUSY" scenarios



#### Summary of CMS SUSY Results\* in SMS framework EPSHEP 2013



Cluster of Excellence

L. Masetti - 02/08/13



### Direct stop-pair production





#### Summary

- Great performance of the LHC and of the detectors in the first 3 years of running
- Plenty of results already published, more in preparation
- Unprecedented precision in flavour physics, some tensions are gone, some new ones appear, some small ones remain
- Top quarks being investigated with very high statistics, still a lot to learn on modelling in simulation
- Entering precision measurements phase in Higgs physics
- Searches for new particles beyond the Standard Model could only set limits, very stringent ones... Did we forget to look for any signature?

39





### Outlook

- Accelerator complex, detector and software(!) consilidation during long shutdown until end of 2014
- Sensitivity to new physics will increase with larger centre of mass energy
- Harsher experimental conditions (higher pile-up!)
- The next year will be needed to complete precision measurements, but also to prepare for run 2
- Will new physics be really around the corner this time?



