Recent results from LHC experiments

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LHC: status and plans



Run 3 6.8 TeV ATLAS, CMS target 250 /fb LHCb 25-30 /fb ALICE 200/pb pp, 7/nb Pb-Pb

Run 4 (H_LHC) High pileup up to $\langle \mu \rangle = 140-200$, high particle multiplicity, plan $\sim 3/ab$

ATLAS Upgrade Phase 1

New Small Wheel muon detector: replacement of previous end-cap CSC based detector with a sTGC+MicroMega

BIS78-RPC muon detector: new RPCs in the barrel to improve the rejection rate of the L1 trigger in the barrelendcap transition region

LAr front-end: new electronics with higher granularity for improved performances of the detector and of the Level-1 Calorimeter electromagnetic triggerskov



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CMS Upgrade Phase 1

BEAM PIPE

Replaced with an entirely new one compatible with the future tracker upgrade for HL-LHC, improving the vacuum and reducing activation.

PIXEL TRACKER

All-new innermost barrel pixel layer, in addition to maintenance and repair work and other upgrades.



BRIL New generation of detectors for monitoring LHC beam conditions and luminosity.



CATHODE STRIP CHAMBERS (CSC)

Read-out electronics upgraded on all the 180 CSC muon chambers allowing performance to be maintained in HL-LHC conditions.

GAS ELECTRON MULTIPLIER (GEM) DETECTORS

An entire new station of detectors installed in the endcap-muon system to provide precise muon tracking despite higher particle rates of HL-LHC.

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HADRON CALORIMETER

New on-detector electronics installed to reduce noise and improve energy measurement in the calorimeter.



SOLENOID MAGNET New powering system to prevent full power cycles in the event of powering problems, saving valuable time for physics during collisions and extending the magnet lifetime.

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Upgrade Phase 1 LHCb

- Major upgrade of all sub-detectors
 - $\rightarrow \mathscr{L}_{\text{peak}} = 2 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$ pile-up ≈ 5
 - \rightarrow fully software trigger for 40MHz readout
 - New pixel-detector **VELO**
 - New **RICH** mechanics, optics, photodetectors
 - Installed for operations in Run 3 - New Silicon strip upstream tracker **UT** (installation at end of year)
 - New SciFi tracker
 - New electronics for **MUON** and **CALO**
 - New luminometer **PLUME**



upgrade

ECAL HCAL

Side View

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New Inner Tracking System (ITS) - 7 barrels, 10 m² silicon tracker based on MAPS (12.5 G pixels)







New Muon Forward Tracker (MFT) - 5 disks based on MAPS

ALICE 2 Upgrade

→ Tracking precision ×3 \rightarrow Pb-Pb rate $\times 50$



New Fast Interaction Trigger (FIT)

 3 detector technologies: interaction trigger, online luminometer, forward multiplicity

New Online/Offline (O2)



New Beampipe smaller diameter (36.4 mm), first detection layer at 20 mm

New Trigger and Readout Upgrade of readout electronics of all detector. new Central Trigger Processor

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Papers in hep-ph with ML,NN etc in title

| 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 21 |
|------|------|------|------|------|------|------|------|------|-----|
| 11 | 14 | 17 | 35 | 55 | 110 | 221 | 373 | 520 | 697 |

In inspire: ft machine learning or t neural network or t deep learning TensorFlow 2015 Scikit-lean 2014 Review in Nature (2018) Machine learning at the energy and intensity frontiers of particle physics,

First events Run 3



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Main part of materials were taken from these conferences

The 10th Annual Large Hadron Collider Physics Conference Mav 16–21, 2022

ICHEP 2022 BOLOGNA

ICHEP 2022 XLI

2022

6 13 07 2022

International Conference orteonal-digh Energy Physics Bologna (Italy)

Main SM processes and X-sec

Overview of CMS cross section results



Main SM processes and measured X-sec



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Measured X-sec vs theory



ATLAS first observation of production WWW

arXiv:2201.13045v1

Measurements of triboson production are a direct test of SM gauge boson self-interactions, deviations would hint at NP

•Triboson states are among the leastunderstood SM processes given the small production cross sections

 \bullet WWW production looked for by ATLAS in 2l (SS) and 3l states

Observed for first time with a significance of 8.0 σ (5.4 expected)

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\sigma WWW(incl) = 820 ± 100(stat) ± 80(syst) fb
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compatible with SM at 2.6 σ (SM: 511 ± 18 fb)



WZ (lvll) polarisation ATLAS-CONF-2022-053, arXiv:2110.11231 (CMS)

- Electroweak VVjj production can proceed in transverse
 (T) or longitudinal (0) polarisation states
- Longitudinal (00) component intertwined with Higgs mechanism VBS unitarization: long term goal
- Probes for the HL-LHC
- currently measurements focus on polarisation or VBS
- New: first measurement of joint polarisation states in inclusive WZ production by ATLAS using DNN
- reconstruction techniques observation of
 double-longitudinal component with > 7σ



Measured joint helicity fractions f00, f0T, fT0 and fTT of the W and Z bosons in W±Z events, compared to NLO OCD fixed-order predictions

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VBS Measurements - W (lv)γ CMS-PAS-SMP-21-011

- Vector boson fusion and vector boson scattering are direct probes
- of boson interactions, both in Standard Model and beyond
- EW Wγjj signal observed with a significance

6.0 (6.8 exp)

cross section for the electroweak Wγjj production in a restricted region is 19.2±4.0 fb





W mass @ LHCb

- Measurement based on shape of p T distribution of muons from W decay
- Simultaneous fit of q/p T of muons from W and of ϕ^* of $Z \to \mu \mu$
- m W = 80354 ± 23stat ± 10exp ± 17theory ± 9PDF MeV
- Important because LHCb probes an acceptance region complementary to that of ATLAS/CMS

Still waiting for CMS result!



The top mass

Direct mass measurements

- Measure m_t^{MC} from reconstructed decay products
- Very high exp. precision : ~0.5 GeV
- Uncertainty in relation to theoretically well-defined mass Ø(0.1-1) GeV



Indirect mass measurements

- Extract m, in well defined renormalisation scheme (pole, MS)
- Measures cross section, either inclusive or differential, corrected for detector effects, and compare to analytical calculations.
- Unfolding of detector/hadronization effects typically yields bigger uncertainty : 1-2 GeV

| ATLAS+CMS Preliminary LHCTOPWG | m _{top} | from cross-section measur Decemb | ement er 202 |
|---|--------------------------|--|------------------------------|
| to | tal stat | $m^{}_{\rm lap} + \rm lot (stat + syst + theo)$ | Ref. |
| ः(tf) inclusive, NNLO+NNLL | | | |
| ATLAS, 7+8 TeV | | 172.9 +2.5 | [1] |
| CMS, 7+8 TeV | | 173.8 +1.7 | [2] |
| CMS, 13 TeV | | $169.9_{-2.1}^{+1.9}(0.1 \pm 1.5_{-1.5}^{+1.2})$ | [3] |
| ATLAS, 13 TeV | - | 173.1 +2.0 | [4] |
| o(tt+1j) differential, NLO | | | |
| ATLAS, 7 TeV | - | 173.7 .2.1 (1.5 ± 1.4 .05) | [5] |
| CMS, 8 TeV | | 169.9 .5.7 (1.1 .5.1 .1.6) | [6] |
| ATLAS, 8 TeV | Hel-I | 171.1 ^{+1,2} (0.4 ± 0.9 ^{+0.7} | [7] |
| o(tt) n-differential, NLO | | 1700 - 10/00 - 00 - 10 | |
| ATLAS, n=1, 8 TeV | 1 1 1 1 | 173.2 ± 1.6 (0.9 ± 0.8 ± 1.2) | [8] |
| CMS, n=3, 13 TeV | H-4 | 170.5 ± 0.8 | [9] |
| m _{top} from top quark decay | [1] IIPUC 1 | 1 (2011) 2109 (J.JHEP 10 (2010) 121 [1] (P.J.C.K) | para est |
| CMS, 7+8 TeV comb. [10] | [2] JHEP O [3] EPJC 7 | a (2016) 200 b) 140 P 11 (2016) 141 [11] B-12 15 a (2016) 200 b) 140 P 11 (2016) 141 [11] B-12 15 | (2018) 07266 (2018) 280 |
| ATLAS, 7+8 TeV comb. [11] | 14 IPJC 8 | 0 (2020) 628 (H) IPAC 77 (2017)-664 | |
| 5 160 165 1 | 70 175 | 180 185 19 | 90 |
| | m [Ge\ | // | |

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Top quark mass (CMS)

• Direct measurement with 5D fit constraining jet uncertainty from W peak $m_t=171.77 \pm 0.38$ GeV

- Measurement from tt+jet cross section
- m_t^pole=172.94± 1.37 GeV
- Measurement of mass distribution and
- m in hadronic decay to boosted jets
- ▶ m_t = 172.76 ± 0.81 GeV





Rare single top production ATLAS-CONF-2022-013 ATLAS-CONF-2022-031

- Rare single top process observation
- Tqγ Single-top quark and a photon of all single-top processes
- Powerful probe of top-EW coupling (and constraints on new physics)
- ▶ semileptonic top-quark decays (t \rightarrow lvb)
- The observed (expected) significance of the tqγ signal is 9.1σ (6.7 σ)



S-channel single top production Lowest cross-section measurement



3.3 σ Observed (3.9 σ expected)

Higgs boson



2207.00043 A portrait of the Higgs boson by the CMS experiment ten years after the discovery

2207.00092 A detailed map of Higgs boson interactions by the ATLAS experiment ten years after the discovery

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Monday 4 Jul 2022, CERN

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Coupling in productions and decays



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- and 12%
- H \rightarrow bb observed with 7.0 σ (7.7 σ)
- H \rightarrow µµ with significances of 2.0 σ (1.7 σ) and Z γ with 2.3 σ (1.1 σ)

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Higgs couplings and H->cc (CMS)

DeepJet: charm tagger for AK4 jets Charm jet properties are in-between udsg and b-jets DNN multiclasifier is used to tag the AK4 jets: DeepJet Efficiencies of the Working Point (for jet with highest charm-tag score):

42% c-jet eff 15% b-jet mistag rate 4% light jet mistag rate

CMS has released two $H{\rightarrow}cc$ analysis with full Run-2 dataset

ggH(cc):

- Exploring H+jet topology with boosted large-cone jets
- Limit set at 45xSM

VH(cc)

• Using two complementary approaches to fully explore the VH(H \rightarrow cc) decay topology (AM4/AK15 jets). QFTHEPC 20.07.2022

• Limit set at 14xSM; 1.1<|kc|<5.5 (95%CL interval) Most stringent limit to date



Higgs Boson Width

- Expected width: Γ = 4.1 MeV
- Direct limit: $\Gamma H < 1.1 \text{ GeV}$

$$\bullet \quad \sigma = \int \frac{1}{(s-m^2) - (\Gamma_H m_H)^2} g_i^2 g_f^2$$

Off-shell data 2l2v, on-shell 4l

- 117 multidimensional distributions were used in the fit
- $H H \rightarrow ZZ(*) \rightarrow 4\ell 2\ell 2\nu$
- From a combined measurement of on-shell and
- off-shell production CMS finds
- evidence for off-shell Higgs production, scenario with no

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- off-shell production is excluded with 3.6σ
- $\Gamma_{H} = 3.2^{+2.4}_{-1.7}$ MeV [arXiv:2202.06923]



CMS

≤140 fb⁻¹ (13 TeV)

2l2v+4l off-shell + 4l on-shell

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15

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CP properties Higgs boson

- ATLAS-CONF-2022-032
- $H \rightarrow \tau + \tau$ (at least one decay hadronically)
- CP-sensitive angular distribution was measured



CMS-PAS-HIG-21-006

CP structure Yukava interaction between Higgs

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and one or two tops was measured

Fractionally CP-odd contribution not

observed



Pure CP-odd coupling excluded at 3.7σ

Pure CP odd ($\phi \tau = \pm 90^\circ$) disfavoured at 3.4 σ OFTHEPC 20.07.2022

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Search for Higgs boson pair production (CMS)

The trilinear self-couplings of the Higgs boson can Be extracted in the process of pair production. Search was done for the ggF and VBF mechanisms. HH -> bbtt and HH \rightarrow bbbb BRSM(HH \rightarrow bbbb) = 33% -> ~1400 events in 138 /fb

Limits on coupling modifiers k_{λ} for HHH (ggF) and for k_2 for VVHH (ggF and VBS)



Heavy Resonance Searches

| ATLAS Exotics Searches* - 95% C | L Upper Exclusion Limits | ATLAS Prelin | minary | | |
|--|--|---|---|--|--|
| Grands. May 2020 | $\int \mathcal{L} dt$ | $= (3.2 - 139) \text{ fb}^{-1}$ $\sqrt{s} = 8, 13$ | 3 lev | Overview of CMS EXO results | |
| Model ℓ, γ Jets T E_T | t[fb ^{-x}] Limit | Referen | | CMS preliminary | 16-140 fb ⁻¹ (13 TeV) |
| ADD $G_{KK} + g/q$ $0 e, \mu$ $1-4j$ Yes 36.1 20 ADD non-resonant $\gamma\gamma$ 2γ $ -36.7$ ADD OBH $ 2j$ $ 37.7$ ADD BH high $\sum p_T$ $\geq 1e, \mu$ $\geq 2j$ $ 37.7$ | 1 M ₀ 7.7 TeV 7 M ₅ 8.5 T 9 M ₆ 8.9 T 2 M ₆ 8.2 T 4 M ₆ 8.2 T | n = 2 1711.0333 V n - 3 HLZ NLO 1707.0414 eV n = 6 1703.0912 V n = 6, M ₀ = 3 TeV, rot BH 1666.022 TEV n = 6, M ₀ = 3 TeV, rot BH 1512.0552 | 301 37 memories 147 We memories 147 Benerative 127 Scatter Organic 285 If = 4 prevelocader (scalter), g ⁺ _{max} × MH q-20 x = 0.010.004) 86 If = 4 prevelocader (scalter), g ⁺ _{max} × MH q-20 x = 0.010.004) | | 14 δμ' 2010 14 δμ' 2010 1500 (1) 4 μ) 1500 (1) |
| RS1 $G_{KK} \rightarrow \gamma\gamma$ 2γ - 36. The Bulk RS $G_{KK} \rightarrow WW/ZZ$ multi-channel 36.1 Bulk RS $G_{KK} \rightarrow WW \rightarrow l vqq$ 1 $e_{+\mu}$ 2 $ 1/1$ Yes 133 Bulk RS $g_{KK} \rightarrow tt$ 1 $e_{+\mu}$ 2 $ 1_{+}2h_{\geq}1_{+}2h_{\geq}2h_{>}2h_{>}2h_{>}2h_{>}2h_{>}2h_{>}2h_{>}2h_{>}2$ | G _{KK} mass 4.1 TeV G _{KK} mass 2.3 TeV G _{KK} mass 2.3 TeV G _{KK} mass 3.8 TeV KK mass 3.8 TeV | $k \overline{M}_{PI} = 0.1 \qquad 1070.041 \\ k \overline{M}_{PI} = 1.0 \qquad 1800.023 \\ k \overline{M}_{PI} = 1.0 \qquad 1800.023 \\ k \overline{M}_{PI} = 1.0 \qquad 12004.146 \\ \Gamma m = 15\% \qquad 1804.108 \\ Tray (1, 1) = 40.11 \\ 1002.062 \\ 1002.061 \\ 1002$ | $ \begin{array}{c} \begin{array}{c} \text{quark compatibases} (B, \eta_{-n}, n-1) \\ \text{Rec} \\ 380 \\ \hline \\ 866 \\ \hline \\ 823 \\ \hline \\ 828 \\ \hline \\ 828$ | 07-4-5 (2011431) 20+1 202-07 (2011437) 20-1 202-07 (2011437) 20-1 202-07 (2011437) 20-1 202-07 (2011437) 20-1 202-07 (2011437) 20-1 | -<24 |
| $\begin{array}{c c c c c c c c c c c c c c c c c c c $ | Kinimas Lo TeV 0 Z' mass 5.1 TeV 1 Z' mass 2.42 TeV 2' mass 2.1 TeV 2' mass 2.1 TeV 2' mass 2.1 TeV 9' W mass 6.0 TeV 10' W mass 3.7 TeV | Гит (1,1), 2(x ⁻¹ - 4)) = 1 (100.369) 1000.062 1709.072 Г/m = 1.2% 2006.051 1900.056 1900.056 1900.056 | 0.0 Team sector mediater (0), 0, - = 0.2, 0, - = 1.0, w 246 Sector mediater (10, 0, - 1, 0, - 1, 0, - 1, 0, w) 242 Sector mediater (10, 0, - 1, 1, 0, - 1 | | 100 m-1 100 m-1 130 m-1 100 m- |
| 90 HVT W' → WZ → (vag model B) 1 e, μ 2 j/1 J Yes 133 HVT V' → WW → qag model B) 0 e, μ 2 J 133 HVT V' → WH → qag model B) 0 e, μ 2 J 133 HVT V' → WH → qag model B) 0 e, μ ≥ 1 b ≥ 2 J 133 LSSM Wg → th 0 0 e, μ 2 J 33 LSSM wg → th 0 0 e, μ 1 = 6 | 9 W/mass 4.3 TeV 9 V/mass 3.8 TeV 1 V/mass 2.93 TeV 9 W/mass 3.2 TeV 1 W/mass 3.2 TeV 1 W/mass 3.2 TeV 1 W/mass 3.2 TeV | $g_V = 3$ 2004,146; $g_V = 3$ 1906,065; $g_V = 3$ 1712,065; $g_V = 3$ CERN-EP-202 $m(N_2) = 0.5$ TeV, $g_1 = g_2$ 1901,105; | 036 60 / dip b4 4 and/. 559 87 / dip b4 4 and/. 516 80 200/073 80 / dip b4 1 is dip b4. 473 400 (gi HZ, n, -) 470 400 (gi HZ, n, -) | (0) | 66 p-1 36 p-1 36 p-3 36 p-3 36 p-3 36 p-3 36 p-3 36 p-3 36 p-3 36 p-1 36 p-3 36 p-1 36 p-1 |
| $\vec{O} \begin{bmatrix} Cl qqq & -2j & -37, \\ Cl fqq & 2e, \mu & -13 \\ Cl fttt & \ge 1e, \mu & \ge 1b, \ge 1j \end{bmatrix} \begin{bmatrix} r_{12} & r_{23} & r_{23} \\ r_{23} r_{23} & r_{23} $ | Operation Operation <t< td=""><td>$\begin{array}{c ccccccccccccccccccccccccccccccccccc$</td><td>0.0 ACO GRI(g), m_e = 6 127 sec sec 200-066 Sec sec 305 sec sec</td><td>11 EF6 BALFORM SPACE BALFORM S</td><td>23 000 02 (J) 14 (w) 14 (w) 16 (m) 13 7 (m) 13 7 (m) 14 (M) 13 7 (m) 14 (M) 15 (M) 1</td></t<> | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 0.0 ACO GRI(g), m _e = 6 127 sec sec 200-066 Sec sec 305 sec sec | 11 EF6 BALFORM SPACE BALFORM S | 23 000 02 (J) 14 (w) 14 (w) 16 (m) 13 7 (m) 13 7 (m) 14 (M) 13 7 (m) 14 (M) 15 (M) 1 |
| $\label{eq:constraint} \begin{array}{cccc} A v i a v v c t r v c r o f i f v s s o f o f e, \mu & 1-4 j & Y s s o o f o e, \mu & 1-4 j & Y s s o s o f o v v v v v v v c r r f O i r o o o o e, \mu & 1-4 j & Y s s s o s o s v v v v v v v r r f O i r o D m o o o e, \mu & 1-4 j & Y s s s o s s s v v v v v v v v$ | 1 meed 1.55 TeV 1 meed 1.67 TeV 2 M. 700 GeV 1 me 3.4 TeV | $\begin{array}{ll} g_{0} = 0.25, \ g_{1} = 1.0, \ m(\chi) = 1 \ {\rm GeV} & 1711.033(\\ g_{1} = 1.0, \ m(\chi) = 1 \ {\rm GeV} & 1711.033(\\ m(\chi) < 150 \ {\rm GeV} & 1600.023(\\ y_{1} < 1.50 \ {\rm GeV} & 1600.023(\\ y_{2} = 0.4, \ \lambda = 0.2, \ m(\chi) = 10 \ {\rm GeV} & 1812.0972 \end{array}$ | 301 app. restance (p = K, K, = − T ∈ R), = − € 30 301 app. restance (p = K, K, = − T ∈ R), = € 30 302 app. restance (p = K, K, = − T ∈ R), = € 30 372 exceled (p = speck, (p, K, = T = 1, K, m)) 40 743 T = € exceled (p = speck, (p, K, = T = 1, K, m)) 40 | 64-74 2202.00071 #4 sgr ⁻¹ sgr 2-43 2201.0124 kit(3) - </td <td>1 100 00 01 (1 17 / 10 / 10 / 10 / 10 / 10 / 10 / 10</td> | 1 100 00 01 (1 17 / 10 / 10 / 10 / 10 / 10 / 10 / 10 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | LC mass 1.4 TeV LO mass 1.56 TeV LO mass 1.03 TeV LO [*] mass 1.03 TeV LO [*] mass 970 GeV | $\begin{array}{lll} \beta = 1 & 1902.003 \\ \beta = 1 & 1902.003 \\ \beta (LQ_3' \to b\tau) = 1 & 1902.003 \\ \beta (LQ_3' \to b\tau) = 0 & 1902.0810 \\ \end{array}$ | 377 310 acceled descript, fr, f = f = 1, L, n = n_1^* 377 acceled descript, f, f = f = f, L, n = n_1^* 377 acceled descript, f, f = f = f, L, n = n_1^* 103 acceled descript, f = f, f = f, L, n = n_1^* 103 acceled descript, f = f, f = f, L, n = n_1^* 103 acceled descript, f = f, f = f, L, n = n_1^* | 000-14 100-000 <td< td=""><td>"</td></td<> | " |
| $ \begin{array}{c} \begin{array}{c} \text{WLO}TT \rightarrow Ht/2T / Wb + X \\ \text{WLO}BT \rightarrow Wt/Zb + X \\ \text{WLO}B, JT_{5/1} T_{5/1} \rightarrow Wt + X \\ \text{VLO}S^{-}_{3} T_{5/1} T_{5/1} \rightarrow Wt + X \\ \text{VLO}S^{-}_{3} T_{5/1} T_{5/1} \rightarrow Wt + X \\ \text{VLO}S^{-}_{4} \neq b \geq 1 \\ \text{VLO}S^{-}_{4} \neq b \geq 1 \\ \text{VLO}S \rightarrow Hb - X \\ \text{VLO}Q \rightarrow Hb + X \\ \text{VLO}S \rightarrow Hb + X \\$ | 1 T mas 1.37 TeV B mas 1.34 TeV Ts ₁₅ mas 1.64 TeV Y mas 1.63 TeV B mas 1.21 TeV Q mass 690 GeV | $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | 343 Wetter the time. Singlet Singlet 10 ⁻¹ sym. Ferniture, J = 1 343 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 0.3 883 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 0.3 344 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 0.3 345 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 0.3 346 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 1.3 347 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 1.3 348 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 1.3 349 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 1.3 341 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 1.1 342 social (2) pair print). complete [10 ⁻¹ sym. Ferniture, J = 1.1 | 0.1321-0332 2222.00494 (36, +40) x412 1121.01197 (3++2), +47" x422 1121.01197 (3++2), +47" x433 1121.01197 (3++2), +47" x434 1121.01197 (3++2), +47" x435 1121.01197 (3++2), +47" x436 1021.0107 (3++2), +47" x436 1020.0127 (2++2) x437 1020.0127 (2++2) | 1277 m ⁻¹ 56 m ⁻¹ 56 m ⁻¹ 77 m ⁻¹ 77 m ⁻¹ 78 m ⁻¹ 78 m ⁻¹ 78 m ⁻¹ 78 m ⁻¹ 79 m ⁻¹ 79 m ⁻¹ 79 m ⁻¹ 79 m ⁻¹ 79 m ⁻¹ 79 m ⁻¹ 70 m ⁻¹ 70 m ⁻¹ 70 m ⁻¹ 70 m ⁻¹ |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | a mass 6.7 TeV 7 a/mass 5.3 TeV 1 b'mass 2.6 TeV 2 mass 3.0 TeV 3 r'mass 1.6 TeV | $\begin{array}{ll} \mbox{only} \ u^* \ \mbox{and} \ \ d^*, \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ | 447 Z., name resource 440 Z., name resource 939 Starton 221 Tuber 2, manual 221 Tuber 2, manual 221 Ur 2, Manual 106, 107 | Bittle-BERS 1322/47/0 (2µ) Stratt 1312/47/0 (2µ) Bittle-BERS Bittle-BERS Stratt 2100 (27/00 (2a, 5µ)) Bittle-BERS Bittle-BERS Bittle-BERS Bittle-BERS | 137 6-1 137 7 8-1 138 7 8-1 139 7 8-1 39 7 8-1 39 7 8-1 140 7 8-1 137 7 8-1 |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | M ^{ell} mass 560 GeV N _{ell} mass 3.2 TeV H ^{ell} mass 870 GeV H ^{ell} mass 400 GeV mati-charped particle mass 1.22 TeV monopole mass 2.37 TeV | $ \begin{array}{c} m(W_{\rm R}) = 4.1 \ {\rm TeV}, g_L = g_R \\ {\rm DY \ production} \\ {\rm DY \ production}, g_I^{\rm AT} = \delta(\tau) = 1 \\ {\rm Tr} \ conduction, g_I^{\rm AT} = \delta(\tau) \\ {\rm DY \ production}, g_I^{\rm AT} = \delta(\tau) \\ {\rm DY \ production}, g_I^{\rm AT} = \delta(\tau) \\ {\rm TeV \ production}, g_I^{\rm AT} = \delta(\tau) \\ {\rm$ | 2016-020 Start (** 1.5%) 354 W1/m Start (**) 364 W1/m Start (**) 373 USM ML/m, M_m - 3M_m 130 Augustor, Catert = 1 | 253-23 1000 AD 114 (3)1 25-23 066 AD 0150 (4)1 253-23 1000 AD 114 35-34 1000 AD 114 253-23 2000 AD 114 35-35 1000 AD 114 253-23 1000 AD 114 35-35 1000 AD 114 | 137 nc -1 137 nc -1 137 nc -1 137 nc -1 137 nc -1 137 nc -1 137 nc -1 136 nc -1 36 nc -1 137 nc -1 |
| $\sqrt{s} = 8$ TeV $\sqrt{s} = 13$ TeV $\sqrt{s} = 13$ TeV partial data full data | 10 ⁻¹ 1 | ¹⁰ Mass scale [TeV] | Selection of observed exclusion limits at 95% C.L. (theory uncertainties are no | t included). mass scale [TeV] | moriond 2022 |

*Only a selection of the available mass limits on new states or phenomena is show †Small-radius (large-radius) jets are denoted by the letter j (J).

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Heavy-resonance searches

- ~100 decay channels studied for various models that predict certain production rate (extra dimensions, gauge bosons, contact interactions, dark matter, heavy quarks, excited fermions, leptoquarks etc)
- Commonly excluded masses ~ 0.4 12 TeV

Searches for W' heavy bosons



Combination of searches for heavy resonances

ATLAS-CONF-2022-028

- Uses 16 (orthogonal) ATLAS publications during 2018 2022
- Combine bosonic decay modes qqqq, vvqq, lvqq, llqq, lvll, qqbb, vvbb, lvbb
- Results are interpreted in terms in the context of Spin-1 Heavy Vector Triplet (I

Weakly coupled HVT-A coupling $\alpha(pp \rightarrow V')$ [fb] 10⁵ ATLAS Preliminary Combined Exp Vs=13 TeV, 139fb⁻¹ Expected Limit (± 1σ) 10⁴ Expected Limit (± 2o) **HVT Model A** VV+VH Exp 10³ ---- II+Iv+tv Exp 10² 10 A.Myagkov OFTHEPC 20.07.20 10-1 = V' \rightarrow VV + VH + II + Iv + τ v 3 5 6 m(V') [TeV]



Searches for Dark Matter (DM) at the LHC

LHC collides pp under well-controlled conditions SM particles can radiate other SM particles "X" (via ISR) Undetected DM \rightarrow imbalance in transverse momentum

> Adopt simplified DM model with a "mediator" V gq (gDM) - mediator coupling to quarks (DM) mmed (mDM) - mass of mediator (DM) ATLAS & CMS: gq=0.25 (S=1), gq=1 (S=0), gDM =1 Γ=minimum width formula



Dark Matter



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Searches for mono-top production fully hadronic final state mass reach for V mediator ~ 2.5 TeV probe also non-resonant model



Exotic Higgs: nMSSM

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A.Myagkov

Long-lived Particles

- LLPs arise in models of SUSY (compressed spectra or weakly-coupled RPV),
- Hidden Valleys, QCD axions, dark matter, dark portal particles, heavy neutral
- leptons...Very popular experimental topic in the last years!
- 1800 LLPs at LHC: $m_{\chi_1^\circ}$ [GeV] 1600 - displaced vertices - long time-of-flight 1400 - unusual energy deposits 1200 1000 Large radius tracking ATL-PHYS-PUB-2017-014 800 600 ATLAS: search for displaced vertices 400 plus jets signatures 10^{-2} OFTHEPC 20.07.2022



Vector-like Quarks and Leptons

▶ Higgs- good agreement with SM: Hard to accommodate new particle masses.

• Vector-like fermions: Dirac masses— decouple from EWK scale at large mass.• Motivated by string theory or extra dimensions.

Additional motivation from recent B flavor anomalies. Relevant: Searches for 3rd gen L!





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CMS: new search for combined b-tau LQ production

- CMS-PAS-EXO-19-016
- Events with τ leptons and at least 1 b-jet selected
- Targeting the single and pair production of LQ
- limits on scalar and vector LQ with varied couplings
- slight excess (~3σ) in categories
- compatible with the $H \rightarrow \tau \tau$
- Result driven by non-res categories



LHCb



New hadrons that are discovered by the LHC experiments LHCb report the observation of new exotic states T_{cc}^+ (3875)

A.Myagko

New tetra- and pentaquark states (LHCb)

Isospin pair of doubly charged and neutral tetraquarks:



Double heavy spectroscopy is now a fact in the LHC physics program!

Narrow peak in the mass spectrum D⁰ D⁰π+ State consistent with ccud Very narrow state, slightly below D*+D⁰ arXiv:2109.01038 arXiv:2109.01056



First $P_{\psi s}^{\Lambda}$ (4438) strange pentaquark LHCb-PAPER-2022-031 (in preparation)

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+ First charm CPV in single channel

- ► CPV in charm small in the standard model −> sensitive to new physics
- ► CPVin charm observed in time integrated difference of CP asymmetries
- $\Delta A \ CP = A \ CP(K + K -) A \ CP(\pi + \pi -) = (-15.4 \pm 2.9) \times 10^{-4}$
- New measurement of A CP(K-K+)=[6.8+-5.4(stat)+-1.6(syst)] 10^-4
- 3.8σ evidence for direct CP violation



Lepton Flavor Universality in the SM

In the Standard Model couplings of leptons to W, Z, γ are independent of flavor by axiom



- Some SM extensions include particles that can cause LFU violation (e.g. LQ, Z')
- Experimental investigation of LFU has been pioneered at LEP $(W \rightarrow l+\nu)$ and at the Bfactories (R(D *))[PRL 109, 101802] showed hints of a tension with the SM

CMS test of LFU in in W boson decav PHYSICAL REVIEW D 105,) 072008 (2022)

A binned maximum likelihood estimate of the W boson branching fractions is performed simultaneously in each event category. The measured branching fractions of the W boson decaying into electron, muon, and tau lepton final statesare(10.83±0.10)%,(10.94±0.08)%, and(10.77±0.21)%, consistent with lepton flavor universality for the weak interaction.



LFU in $b \rightarrow sll$

 \blacktriangleright $b \rightarrow sll$ are FCNC, forbidden at tree level and therefore very rare

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- ▶ LHCb has investigated *RK* +, *RK* *0, *RpK*, *RK* *+, *RK*
- Coherent set of b->sll tensions



QCD evolution via photon studies @ALICE

Prompt direct photons produced in initial hard-parton scatterings,

prior to the formation of the QGP

Thermal photons from QGP phase

Thermal photons from hadron gas

Thermal photons excellent probe for QGP temperature

Extract effective temperature from slope of exponential photon

Photon spectrum well described by calculations that include Prompt photons from hard scattering and thermal photons. These calculations suggest a dominance of thermal photons at Pt< 3 GeV



Energy loss of charm and beauty quarks in the QGP@ALICE



Beauty R AA measured down to p T = 1GeVALI-PUB-501659 for the rst time ; large suppression for p T > 5GeV

Data well described by models that include collisional and radiative energy loss and quark recombination, in addition to

fragmentation as a hadronization mechanism

A.Myagkov

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[Nature 605, 440 (2022)]

Anomaly Detection

► This is a unique time in history: we have no solid prediction of what might come next (unlike W/Z, top, Higgs). Robin Erbacher

- New approach: anomaly detection via
- bump hunting (a la $H \rightarrow \gamma \gamma$) with background from data
- unsupervised networks (autoencoders, adversarial nets, ...)
- weakly or semi-supervised networks

Conclusion

- Run3 is started 5 of July, ATLAS and CMS plan to add 250/fb to data
- ► Very broad spectrum of the tasks.
- Several hints give a hope.

This is a great time to search for surprises!