

# Flavour physics with electroweak-penguin and semileptonic decays at Belle and Belle II

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# Belle and Belle II experiments

## • Belle @ KEKB:

- one of the first generation B factories, **771 x 10<sup>6</sup> BB** pairs collected in ~ 10 years of data taking
- experiment goal: measurement of **CP violation in B** meson system but they did much more

## • Belle II @ SUPERKEKB:

- from KEKB to SuperKEKB: aim to collect **50 ab**-1 (~50x Belle) by 2031 reaching ~60 x 10<sup>34</sup> cm<sup>-2</sup> s<sup>-1</sup> (~30x KEKB)
- Upgrade of Belle detector: similar or better performances wrt Belle in much higher machine background/event rate environments
- Total integrated luminosity as of today: 213 fb<sup>-1</sup>, >120 fb<sup>-1</sup> in February-June 2021
- Current world record instantaneous luminosity = 3.1x10<sup>34</sup> cm<sup>-2</sup> s<sup>-1</sup> (KEKB world record: 2. 1 x 10<sup>34</sup> cm<sup>-2</sup> s<sup>-1</sup>)



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## Semileptonic and electroweak penguin decays at Belle II

- sector, in a complementary way wrt other experiments
- Belle II physics program.





[ will mainly focus on this ]

• Large Belle II dataset will allow to continuing investigating the flavour

• Electroweak and semileptonic B decays are among the **golden channels** of



# B meson pair reconstruction: Tagged analisys

- Reconstruct one B in the event  $(B_{taq})$  and constraint the kinematic of the other B (B<sub>sig</sub>)
- B<sub>tag</sub> reconstruction with **Full Event Interpretation** (FEI): multivariate algorithm with hierarchical approach to reconstruct O(200) hadronic and **semileptonic** decay channels
- $B_{sig}$  reconstruction: once the  $B_{tag}$  has been reconstructed, search for the signal signature in the rest of the event
- Knowing the initial energy, the missing energy associated to the **neutrinos** can be computed





Hadronic FEI

Keck T. et al. Comput Softw Big Sci (2019) 3: 6.



# B meson pair reconstruction: Untagged analysis

- Search for the final state particles consistent with the signature (and eventually constraint the kinematic of the rest of the event)
  - exclusive B<sub>sig</sub> reconstruction: all final state particles are reconstructed (e.g.  $B^+ \rightarrow K^+ \ell^+ \ell^-$ ), can apply kinematic constraint to ROE that should be compatible with a B meson
  - **inclusive B**<sub>sig</sub> reconstruction: one/few final state particle(s) are reconstructed (e.g.  $B \rightarrow X_s^* \gamma$ ), the ROE is the other B in the event + what is left from signal reconstruction

















Semileptonic decays

# $b \rightarrow c \ell v$ : latest Belle R(D(\*)) measurement

• Sensitive probes for New Physics (leptoquarks, two Higgs doublets etc.) which could impact lepton flavour universality ratios:

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_{\tau})}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_{\ell})}$$

- **Belle analysis** (711 fb<sup>-1</sup>)
  - Tag side reconstructed with Semileptonic FEI,  $\tau$  in purely leptonic modes
  - Signal extracted from 2D fit to BDT output and  $E_{ECL}$ :
    - **E**<sub>ECL</sub> = neutral energy deposited in the calorimeter not associated to signal nor to tag side, key ingredient in analysis with missing energy
  - Most precise measurements reported to date

 $\mathcal{R}(D) = 0.307 \pm 0.037 \pm 0.016$  $\mathcal{R}(D^*) = 0.283 \pm 0.018 \pm 0.014$ 

(where  $\ell = e$  and  $\mu$ )







## $b \rightarrow c \ell v$ : toward R(D(\*)) Belle II measurement (II)

## • Measurement of normalisation channel with 34.6 fb<sup>-1</sup> using hadronic FEI



 $\mathcal{B}(\overline{B}^0 \to D^{*+} \ell^- \overline{\nu}_l) = (4.51 \pm 0.41_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.45_{\pi_s})\%$ 

In agreement with world average





main systematic from soft  $\pi$ reconstruction, will improved in the future with auxiliary measurements



- Plethora of  $\tau/\ell$  ratio measurements from LHCb and Belle
- On **R(D(\*))**, (sub)-% level precision can be reached
- with Belle II data

• (a) Belle, one of the dominant systematics from D\*\* background, can be studied in more detail

## $b \rightarrow u \ell v$ : new Belle measurements

- Challenging due to  $B \rightarrow X_c \ell v$  contamination: clear separation through kinematic variables, e.g. lepton momentum endpoint or low M<sub>X</sub>
- Full Reconstruction of hadronic B<sub>tag</sub> (NIM A 654, 432-440 (2011))
- Inclusive measurement: measure the 6 kinematic variables in the phase space of  $E_B > 1$ GeV  $\mathbf{q}^{2}$ ,  $\mathbf{E}_{\mathbf{I}}^{\mathbf{B}}$ ,  $\mathbf{M}_{\mathbf{x}'}$ ,  $\mathbf{M}_{\mathbf{x}}^{2}$ ,  $\mathbf{P}_{\mathbf{x}}$ ,  $\mathbf{P}_{\mathbf{x}}^{\mathbf{D}}$  (light-cone momenta:  $\mathbf{P}_{\pm} = \mathbf{E}_{\mathbf{x}} \mp |\mathbf{p}_{\mathbf{x}}|$ )







Necessary input for future **modelindependent determinations** of |V<sub>ub</sub>|







Radiative and Electroweak penguin decays

 $b \leq W W \leq s$ u.c +b / s

# $b \rightarrow s\gamma$ state of the art

- $b \rightarrow s\gamma$  transitions excellent probe for physics beyond the Standard Model
  - BF ~ 10<sup>-5</sup>, large uncertainty in the exclusive measurements due to form factors, which cancels in CP and isospin asymmetries (ratios of rates)
- State of the art, best measurements from **Belle**:



• Can be improved with the larger data set by Belle II in future

[1] Phys. Rev. D 99, 032012 (2019), 711 fb<sup>-1</sup>, [2] Phys.Rev.D 91 (2015) 5, 052004, 711 fb<sup>-1</sup>, [3] PRL 103, 241801 (2009), 605 fb<sup>-1</sup>, [4] Phys. Rev. Lett. 119, 191802 (2017), 711 fb<sup>-1</sup>



## $B \rightarrow X s \gamma$

10-12% **[2]**, **[3]** 

consistent with zero [1]





# $b \rightarrow s\gamma$ : first results at Belle II (I)

- $B \rightarrow K^* \gamma$  branching fraction measurement, with 63 fb<sup>-1</sup>
  - full reconstruction of the decay chain: charged and neutral K\* + high energy photon

- Measured BR consistent with world average values at 1-2  $\sigma$ 
  - CP and isospin asymmetry measurement foreseen in the next iterations of the analysis



# $b \rightarrow s\gamma$ : first results at Belle II (II)

- $B \rightarrow X_s \gamma$  with untagged method, 63 fb<sup>-1</sup>
  - Reconstruct only high energy γ
     from signal side, monochromatic particle is expected

- Extract signal from photon energy spectrum
- **Excess** visible in the expected signal region





 $B \rightarrow K^{(*)}$  II:  $R(K^{(*)})$  status of the art



- LHCb (arXiv:2103.11769) at 3.1**σ** level



- **R(K)** measured in q<sup>2</sup> bins, in agreement with SM expectations
- Statistically limited



# $B \rightarrow K^{(*)}$ II: status and perspectives at Belle II

- Search for  $B^+ \rightarrow K^+ \ell^+ \ell^-$  with <u>63 fb<sup>-1</sup></u> of Belle Data
  - rehearsing analysis using  $B^+ \rightarrow J/\Psi (\ell^+ \ell^-) K^+$  control sample (same final state but large BR)
- Signal yield extracted from 2D fit to  $M_{bc}$  and  $\Delta E$ , 2.7 $\sigma$  significance

• 
$$N_{sig} = 8.6^{+4.3}_{-3.9}(stat) \pm 0.4(syst)$$

- Long term perspectives for **R(K(\*))**:
  - LHCb with full luminosity (~2035, 300fb<sup>-1</sup>) to full Belle II data sample
  - In the high q<sup>2</sup> Belle II precision will reach **fe**



• LHCb with full luminosity (~2035, 300fb<sup>-1</sup>) is expected to have better precision in the low q<sup>2</sup> wrt



## $b \rightarrow sv\overline{v}$ : state of the art prior to Moriond2021

• SM predictions:

T. Blake et al, Prog. Part.Nucl. Phys.92, 50 (2017)

BR $(B^+ \to K^+ \nu \bar{\nu})_{\rm SM} = (4.6 \pm 0.5) \times 10^{-6}$ ,

 $BR(B^+ \to K^{*+} \nu \bar{\nu})_{SM} = (8.4 \pm 1.5) \times 10^{-6},$ 

- Possible enhancement in NP scenarios, e.g. Leptoquark models explaining flavour anomalies
- BaBar and Belle key ingredient: **hadronic** and **semileptonic tag** side reconstruction

	UL @ 90% CL (10 <sup>-5</sup> )	
<b>B</b> +→ <b>K</b> <sup>+</sup> υ $\overline{\nu}$	1.6	<u>BaBar</u> , HAD+
<b>B</b> +→ <b>K</b> <sup>*+</sup> $v\overline{v}$	4.0	<u>Belle</u> , HAD
<b>Β∘→Κ°</b> υ <i>υ</i> ¯	2.6	<u>Belle</u> , SL
<b>B</b> •→ <b>K</b> <sup>∗</sup> <sup>o</sup> υ $\overline{v}$	1.8	<u>Belle</u> , SL



# $B^+ \rightarrow K^+ v \bar{v} \bar{v}$ measurement (a) Belle II (1)

## **NOVEL INCLUSIVE APPROACH on <u>63 fb-1</u> of Belle** II data:

- Signal kaon = highest  $p_T$  track
- Associate all other tracks and clusters to other B in the event
- Use multivariate approach (2 BDTs in cascade) based on kinematics, event shape and vertexing variables to suppress background
- **Signal efficiency** ~ **4.3%** (SM signal)

Belle II coll., arXiv:2104.12624 submitted to journal









# $B^+ \rightarrow K^+ v \bar{v} \bar{v}$ measurement (a) Belle II (II)

- Check data-simulation agreement in BDTs output using  $B^+ \rightarrow J/\psi(\mu^+\mu^-)K^+$ control sample
- Data/MC ratio in fit region: 1.06 ± 0.10

Extract signal from simultaneous maximum likelihood fit to on-resonance + off- resonance data (taken 60MeV below Y(4S) resonance) in bins of  $P_T(K^+)$  and second BDT (BDT<sub>2</sub>):

Signal strength:  $\mu = 4.2^{+2.9}_{-2.8}(\text{stat})^{+1.8}_{-1.6}(\text{syst})$ 

- consistent with SM exp ( $\mu$ =1) at 1  $\sigma$
- consistent with background-only hypothesis at 1.3  $\sigma$
- Leading systematics: **background normalisation** uncertainty can be also reduced with increasing statistics





# $B^+ \rightarrow K^+ v \bar{v} \bar{v}$ measurement (a) Belle II (III)

- Comparing theory and experiments:

 $\mathscr{B}(B^+ \to K^+ \nu \bar{\nu}) = 1.9^{+1.6}_{-1.5} \times 10^{-5}$ 

- When converted to the same luminosity, our measurement is better<sup>\*)</sup> than semileptonic tagging by 10-20%
- ... and than hadronic tagging by a factor 3.5!

\*) assuming the total uncertainty on the branching-fraction scales with  $1/\sqrt{L}$ 

channels in progress



• Room for **improvement** in K<sup>+</sup> channel, application of inclusive method to **other** 

# Conclusions

- Belle is still producing interesting results, moreover the accumulated knowledge on MC modelling, analysis techniques, etc. will be beneficial for future measurements by e.g. Belle II or LHCb
- of a "Super B factory"
  - plan to record **50 ab-1**, 30x Belle dataset, by **2031**
- well
- In the SL and EWP sector:
  - **complementarity** with LHCb
- Belle II is starting playing a role in understanding the **flavour physics puzzle**.

• SuperKEKB has set a new world record in instantaneous luminosity of **3.1x10<sup>34</sup> cm<sup>-2</sup> s<sup>-1</sup>** and is entering the regime

• As proven by performed measurements in agreement with world averages, Belle II detector is performing very

preliminary results on channels of interest and competitive measurements based on **new analysis technique** 

•  $\mathbf{B}^+ \rightarrow \mathbf{K}^+ v \overline{v}$  inclusive measurement in the same ballpark wrt Belle and BaBar ones with ~1/10 Belle statistics

# Extra stides



- the low q<sup>2</sup> wrt to full Belle II data sample,
- In the high q<sup>2</sup> Belle II precision at **few %** level

• LHCb with full luminosity ( $\sim 2035$ ,  $300 \text{ fb}^{-1}$ ) is expected to have better precision in





# **Belle II - LHCb Comparison**

## **Belle II**

Higher sensitivity to decays with photons and neutrinos (e.g.  $B \rightarrow Kvv, \mu v$ ), inclusive decays, time dependent CPV in  $B_{d_{r}} \tau$ physics.

## **LHCb**

Higher production rates for ultra rare B, D, & K decays, access to all b-hadron flavours (e.g.  $\Lambda_b$ ), high boost for fast  $B_s$  oscillations.

Overlap in various key areas to verify discoveries.

## **Upgrades**

Most key channels will be stats. limited (not theory or syst.). LHCb scheduled major upgrades during LS3 and LS4. Belle II formulating a 250 ab<sup>-1</sup> upgrade program post 2028.

## **Observable**

## CKM precision, new physics in CP $\sin 2\beta/\phi_1 (B \rightarrow J/\psi K_S)$



*arXiv:* 1808.08865 (Physics case for LHCb upgrade II), PTEP 2019 (2019) 12, 123C01 (Belle II Physics Book)

Beauty 2020

+ Important contributions on B and D flavour physics from ATLAS, CMS, BESIII.

Current Belle/ Babar	2019 LHCb	Belle II (5 ab <sup>-1</sup> )	elle II Belle II LHCb 5 ab <sup>-1</sup> ) (50 ab <sup>-1</sup> ) (23 fb <sup>-1</sup> ) Belle II Upgrad (250 ab <sup>-1</sup> )		Belle II Upgrade (250 ab <sup>-1</sup> )	LHCb upgrade II (300 fb <sup>-1</sup> )	
<u>PViolation</u>							
0.03	0.04	0.012	0.005	0.011	0.002	0.003	
13°	5.4°	4.7°	1.5°	1.5°	0.4°	0.4°	
4°	_	2	0.6°	_	0.3°	_	
4.5%	6%	2%	1%	3%	<1%	1%	
_	49 mrad	_	_	14 mrad	_	4 mrad	
0.08	0	0.03	0.015	0	0.007	0	
0.15	_	0.07	0.04	_	0.02		
enguins, LFUV							
0.32	0	0.11	0.035	0	0.015	0	
0.24	0.1	0.09	0.03	0.03	0.01	0.01	
6%	10%	3%	1.5%	3%	<1%	1%	
24%, –	_	9%, 25%	4%, 9%	_	1.7%, 4%	_	
_	90%	_	_	34%	_	10%	
_	8.5×10-4	_	5.4×10-4	1.7×10-4	2×10-4	0.3×10-4	
1.2%	_	0.5%	0.2%	_	0.1%	_	
<120×10-9	_	<40×10-9	<12×10-9	_	<5×10-9	_	
<21×10-9	<46×10-9	<3×10-9	<3×10-9	<16×10-9	<0.3×10-9	<5×10-9	
			• Possible	in similar d	channels la	wer nrecisi	

nur channels, lower precision – *Not competitive*.

Phillip URQUIJO

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# Indirect searches: ATLAS

## • <u>https://twiki.cern.ch/twiki/bin/view/AtlasPublic</u>

- <u>https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-009/fig\_01.png</u>
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2020-020/fig 23.png

## ATLAS Exotics Searches\* - 95% CL Upper Exclusion Limits

Status: March 2021

0

**ATLAS** Preliminary  $\sqrt{s} = 8, 13 \text{ TeV}$  $\int \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$  $\ell, \gamma$  Jets  $\dagger E_T^{\text{miss}} \int \mathcal{L} dt [fb^{-1}]$ Model Reference Limit ADD  $G_{KK} + g/q$ 0 e, μ, τ, γ 1 – 4 j 139 2102.10874 Yes **11.2 TeV** *n* = 2 ADD non-resonant  $\gamma\gamma$ 36.7 2γ 8.6 TeV n = 3 HLZ NLO 1707.04147 ADD QBH 2 j 37.0 **8.9 TeV** *n* = 6 1703.09127 \_ **9.55 TeV** *n* = 6, *M*<sub>D</sub> = 3 TeV, rot BH ADD BH multijet ≥ 3 j 3.6 \_ 1512.02586 RS1  $G_{KK} \rightarrow \gamma \gamma$ 2γ 139  $k/\overline{M}_{Pl} = 0.1$ 2102.13405 4.5 TeV \_ 36.1 Bulk RS  $G_{KK} \rightarrow WW/ZZ$ 2.3 TeV  $k/\overline{M}_{Pl} = 1.0$ multi-channel 1808.02380 Bulk RS  $G_{KK} \rightarrow WV \rightarrow \ell \nu qq$ 2j/1J 2.0 TeV Yes 139  $k/\overline{M}_{Pl} = 1.0$ 1 e,μ 2004.14636 K mass Bulk RS  $g_{KK} \rightarrow tt$ 1 e,  $\mu$   $\geq$  1 b,  $\geq$  1J/2j Yes 36.1 mas  $\Gamma/m = 15\%$ 1804.10823 2UED / RPP 1.8 TeV Tier (1,1),  $\mathcal{B}(A^{(1,1)} \to tt) = 1$  $1 e, \mu \ge 2 b, \ge 3 j$  Yes 36.1 1803.09678  $\mathsf{SSM}\ Z' \to \ell\ell$ 2 e, µ 5.1 TeV 1903.06248 139 SSM  $Z' \rightarrow \tau \tau$ 36.1 2 τ 2.42 TeV 1709.07242 mass 36.1 139 139 Leptophobic  $Z' \rightarrow bb$ 2 b 2.1 TeV \_ 1805.09299 mass 0 e, µ  $\geq 1 \text{ b, } \geq 2 \text{ J}$  Yes Leptophobic  $Z' \rightarrow tt$ 4.1 TeV  $\Gamma/m = 1.2\%$ 2005.05138 mass 1 e, µ Yes 6.0 TeV SSM  $W' \rightarrow \ell v$ 1906.05609 — " mas SSM  $W' \rightarrow \tau v$  $1\tau$ Yes 36.1 3.7 TeV 1801.06992 2 j / 1 J HVT  $W' \rightarrow WZ \rightarrow \ell \nu q q$  model B Yes 139 4.3 TeV 2004.14636 1 e,μ  $g_V = 3$ 139 139 HVT  $Z' \rightarrow ZH$  model B 0-2 e, µ 1-2 b Yes 3.2 TeV  $g_V = 3$ ATLAS-CONF-2020-043 nass  $0 e, \mu \ge 1 b, \ge 2 J$ 3.2 TeV HVT  $W' \rightarrow WH$  model B  $g_V = 3$ 2007.05293 mass LRSM  $W_R \rightarrow tb$ multi-channel 36.1 3.25 TeV 1807.10473 mass  $m(N_R) = 0.5 \text{ TeV}, g_L = g_R$ LRSM  $W_R \rightarrow \mu N_R$ 1 J 2μ 80 5.0 Te\ 1904.12679 37.0 **21.8 TeV** η<sub>L</sub> CI qqqq 2 j 1703.09127 Clℓℓqq 2 e, µ 139 35.8 TeV 2006.12946  $\eta_{II}$ CI eebs 139 1.8 TeV ATLAS-CONF-2021-012 2 e 1 b \_  $g_* = 1$ Cl µµbs 2μ 139 2.0 TeV 1 b  $g_* = 1$ ATLAS-CONF-2021-012 ≥1 e, $\mu$ 2.57 TeV  $|C_{4t}| = 4\pi$ CI tttt ≥1 b, ≥1 j Yes 36.1 1811.02305 Axial-vector med. (Dirac DM) 1 – 4 j 2.1 TeV  $g_q=0.25, g_{\chi}=1, m(\chi)=1 \text{ GeV}$  $0 e, \mu, \tau, \gamma$ Yes 139 2102.10874 376 GeV  $g_q=1, g_{\chi}=1, m(\chi)=1 \text{ GeV}$ Pseudo-scalar med. (Dirac DM) 139 0 e,μ,τ,γ 1 – 4 j Yes 2102.10874 Vector med. Z'-2HDM (Dirac DM)  $0 e, \mu$ 2 b Yes 139 3.1 Te  $\tan\beta=1, g_Z=0.8, m(\chi)=100 \text{ GeV}$ TLAS-CONF-2021-006 Pseudo-scalar med. 2HDM+a 0 e,μ 2 b Yes 139 520 Ge\  $\tan\beta=1, g_{\chi}=1, m(\chi)=10 \text{ GeV}$ ATLAS-CONF-2021-006 Scalar reson.  $\phi \rightarrow t\chi$  (Dirac DM) 0-1  $e, \mu$ 1 b, 0-1 J Yes 36.1 3.4 Te  $y=0.4, \lambda=0.2, m(\chi)=10 \text{ GeV}$ 1812.09743 Scalar LQ 1<sup>st</sup> gen ≥ 2 j 1.8 TeV eta=12006.05872 Yes 139 2 e ≥ 2 j 139 Scalar LQ 2<sup>nd</sup> gen  $2\,\mu$ Yes eta=11.7 TeV 2006.05872 1.2 TeV  $\mathcal{B}(LQ_3^u \to b\tau) = 1$  $1\tau$ 2 b Yes 139 ATLAS-CONF-2021-008 Scalar LQ 3<sup>rd</sup> gen  $0 e, \mu \ge 2 j, \ge 2 b$  Yes 1.24 TeV  $\mathcal{B}(LQ_3^u \to tv) = 1$ Scalar LQ 3<sup>rd</sup> gen 139 2004.14060 Scalar LQ 3<sup>rd</sup> gen  $\geq 2e, \mu, \geq 1\tau \geq 1 \text{ j}, \geq 1 \text{ b}$  – 139 1.43 TeV  $\mathcal{B}(LQ_3^d \to t\tau) = 1$ 2101.11582  $0 \ e, \mu, \ge 1\tau \ 0 - 2 \ j, 2 \ b \ Yes$ 139 1.26 TeV  $\mathcal{B}(LQ_3^d \to bv) = 1$ 2101.12527 Scalar LQ 3<sup>rd</sup> gen VLQ  $TT \rightarrow Ht/Zt/Wb + X$ 1.37 TeV SU(2) doublet multi-channel 36.1 1808.02343 VLQ  $BB \rightarrow Wt/Zb + X$ 1.34 TeV SU(2) doublet 1808.02343 multi-channel 36.1 mass Yes  $\mathcal{B}(T_{5/3} \rightarrow Wt) = 1, c(T_{5/3}Wt) = 1$ VLQ  $T_{5/3}T_{5/3}|T_{5/3} \rightarrow Wt$ 2(SS)/≥3 *e*,*µ* ≥1 b, ≥1 j 36.1 1.64 TeV 1807.11883 13 mass  $1^{'}e, \mu^{'} \geq 1 \text{ b}, \geq 1 \text{ j}$  Yes  $\mathcal{B}(Y \to Wb) = 1, c_B(Wb) = 1$  $\mathsf{VLQ} \ Y \to Wb + X$ 36.1 1.85 TeV 1812.07343 mass VLQ  $B \rightarrow Hb + X$ 0 e,µ  $\geq$  2 b,  $\geq$  1j Yes 79.8 1.21 TeV singlet,  $\kappa_B = 0.5$ ATLAS-CONF-2018-024 VLQ  $QQ \rightarrow WaWa$ 1 e,μ ≥ 4 j Yes 20.3 1509.04261 Excited quark  $q^* \rightarrow qg$ 139 6.7 TeV 2 j only  $u^*$  and  $d^*$ ,  $\Lambda = m(q^*)$ 1910.08447 Excited quark  $q^* \rightarrow q\gamma$ 1γ 36.7 5.3 TeV only  $u^*$  and  $d^*$ ,  $\Lambda = m(q^*)$ 709.10440 \_ Excited quark  $b^* \rightarrow bg$ 36.1 1 b, 1 j 2.6 TeV 1805.09299 \_ -Excited lepton  $\ell^*$ 3 e, µ 20.3  $\Lambda = 3.0 \text{ TeV}$ 1411.2921 3.0 Te \_ \_ 1.6 TeV 1411.2921 Excited lepton  $v^*$ 3 e,μ,τ  $\Lambda = 1.6 \text{ TeV}$ \_ \_ 20.3 Type III Seesaw 1 e,μ 790 GeV 20008.07949 ≥ 2 j Yes 139  $m(W_R) = 4.1 \text{ TeV}, g_L = g_R$ LRSM Majorana v 2μ 36.1 3.2 TeV 1809.11105 2 j Higgs triplet  $H^{\pm\pm} \rightarrow \ell \ell$ 2,3,4 *e*, *µ* (SS) 36.1 870 GeV DY production 1710.09748 Higgs triplet  $H^{\pm\pm} \rightarrow \ell \tau$ DY production,  $\mathcal{B}(H_{L}^{\pm\pm} \rightarrow \ell \tau) = 1$ 3 e,μ,τ 20.3 1411.2921 \_ DY production, |q| = 5eMulti-charged particles 36.1 1812.03673 1.22 TeV charged particle mass Magnetic monopoles DY production,  $|g| = 1g_D$ , spin 1/2 2.37 TeV 1905.10130 34.4 pole mass √s = 13 TeV √s = 13 TeV √s = 8 Te\ **10**<sup>-1</sup> 10 partial data full data Mass scale [TeV]

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

## ATLAS SUSY Searches\* - 95% CL Lower Limits July 2020

		Model	S	ignatur	e j	∫ <i>L dt</i> [fb <sup>-</sup>	1]	Mass limit					Reference
2	ŝ	$\tilde{q}\tilde{q}, \tilde{q}  ightarrow q \tilde{\chi}_1^0$	0 e, µ mono-jet	2-6 jets 1-3 jets	$E_T^{ m miss} \ E_T^{ m miss}$	139 36.1	<ul> <li><i>q̃</i> [10× Degen.]</li> <li><i>q̃</i> [1×, 8× Degen.]</li> </ul>	0.43	0.71		1.9	$\mathfrak{m}( ilde{\mathcal{X}}_1^0){<}400~\mathrm{GeV}$ $\mathfrak{m}( ilde{q}){=}\mathfrak{m}( ilde{\mathcal{X}}_1^0){=}5~\mathrm{GeV}$	ATLAS-CONF-2019-040 1711.03301
rche		$\tilde{g}\tilde{g},\tilde{g}\!\rightarrow\!q\bar{q}\tilde{\chi}_{1}^{0}$	0 <i>e</i> , <i>µ</i>	2-6 jets	$E_T^{\rm miss}$	139	ε σ σ σ σ		Forbidden		2.35 1.15-1.95	$m(\tilde{\chi}_1^0)=0 \text{ GeV} \ m(\tilde{\chi}_1^0)=1000 \text{ GeV}$	ATLAS-CONF-2019-040 ATLAS-CONF-2019-040
Co Co	ŭ O D	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}W\tilde{\chi}_1^0$	1 e,μ ee,μμ	2-6 jets 2 iets	Fmiss	139 36 1	ğ o			1.2	2.2	$m(\tilde{\chi}_1^0) < 600 \text{ GeV}$ $m(\tilde{\chi}_1^0) = 50 \text{ GeV}$	ATLAS-CONF-2020-047
hicity	MIGNI	$\begin{array}{l} gg, g \to qq(\iota \iota \chi_1) \\ \tilde{g}\tilde{g}, \tilde{g} \to qqWZ\tilde{\chi}_1^0 \end{array}$	0 e, μ SS e, μ	7-11 jets 6 jets	$E_T$ $E_T^{\text{miss}}$	139 139	5 755 75		1	1.15	1.97	$m(\tilde{\chi}_1^0) = 30 \text{ GeV}$ $m(\tilde{\chi}_1^0) < 600 \text{ GeV}$ $m(\tilde{\chi}_1^0) = 200 \text{ GeV}$	ATLAS-CONF-2020-002 1909.08457
		$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t t \tilde{\chi}_1^0$	0-1 <i>e</i> ,μ SS <i>e</i> ,μ	3 <i>b</i> 6 jets	$E_T^{ m miss}$	79.8 139	o iso iso			1.25	2.25	$m(\tilde{\chi}_1^0) < 200 \text{ GeV}$ $m(\tilde{\chi}_1^0) < 200 \text{ GeV}$ $m(\tilde{g}) - m(\tilde{\chi}_1^0) = 300 \text{ GeV}$	ATLAS-CONF-2018-041 1909.08457
		$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 {\rightarrow} b\tilde{\chi}_1^0/t\tilde{\chi}_1^{\pm}$		Multiple Multiple		36.1 139	$egin{array}{ccc}  ilde{b}_1 & Forbic \  ilde{b}_1 \end{array}$	lden Forbidden	0.9 0.74		$m( ilde{\mathcal{X}}_1^0)=200G$	$m(\tilde{\chi}_{1}^{0})$ =300 GeV, BR $(b\tilde{\chi}_{1}^{0})$ =1 ieV, $m(\tilde{\chi}_{1}^{\pm})$ =300 GeV, BR $(t\tilde{\chi}_{1}^{\pm})$ =1	1708.09266, 1711.03301 1909.08457
ks	no	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 \rightarrow b h \tilde{\chi}_1^0$	0 <i>e</i> , μ 2 τ	6 <i>b</i> 2 <i>b</i>	$E_T^{ m miss} \ E_T^{ m miss}$	139 139	$egin{array}{ccc} eta_1 & Forbidden \ eta_1 & eta_1 & \end{array}$		0 0.13-0.85	).23-1.35	$\Delta m( ilde{\mathcal{X}}_2^{\prime})$	$(\tilde{\chi}^0_1, \tilde{\chi}^0_1) = 130 \text{ GeV}, m(\tilde{\chi}^0_1) = 100 \text{ GeV}$ $(\tilde{\chi}^0_2, \tilde{\chi}^0_1) = 130 \text{ GeV}, m(\tilde{\chi}^0_1) = 0 \text{ GeV}$	1908.03122 ATLAS-CONF-2020-031
quar	lucti	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$	0-1 <i>e</i> , μ	$\geq 1$ jet	$E_T^{\text{miss}}$	139	$\tilde{t}_1$	0 44.0	50	1.25		$m(\tilde{\chi}_1^0)=1 \text{ GeV}$	ATLAS-CONF-2020-003, 2004.14060
n. St	proc	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\chi_1^\circ$ $\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 by, \tilde{\tau}_1 \rightarrow \tau \tilde{G}$	$1 e, \mu$ $1 \tau + 1 e, \mu, \tau$	3 jets/1 <i>b</i>	$E_T^{\text{miss}}$ $E_T^{\text{miss}}$	139 36.1	$t_1$ $\tilde{t}_1$	0.44-0.3		1.16		m(𝑋₁)=400 GeV m(𝑣₁)=800 GeV	ATLAS-CONF-2019-017 1803.10178
<sup>1</sup> ge	ect	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c \tilde{\chi}_1^0 / \tilde{c} \tilde{c}, \tilde{c} \rightarrow c \tilde{\chi}_1^0$	0 <i>e</i> , <i>µ</i>	2 c	$E_T^{miss}$	36.1	č		0.85			$m(\tilde{\chi}_1^0)=0~GeV$	1805.01649
376	dii		0 <i>e</i> , <i>µ</i>	mono-jet	$E_T^{\rm miss}$	36.1	$\widetilde{t}_1$ $\widetilde{t}_1$	0.46 0.43				$ \begin{array}{l} m(\tilde{t}_1,\tilde{c})\text{-}m(\tilde{\chi}_1^0) = \!$	1805.01649 1711.03301
		$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	1-2 <i>e</i> , μ	1-4 <i>b</i>	$E_T^{\text{miss}}$	139	$\tilde{t}_1$		0.067-	1.18	~0	$m(\tilde{\chi}_2^0)=500 \text{ GeV}$	SUSY-2018-09
		$t_2 t_2, t_2 \rightarrow t_1 + Z$	3 e, µ	1 <i>b</i>	$E_T^{\text{mass}}$	139		Forbidden	0.86	_	$m(\mathcal{X}_1^0)$ =	=360 GeV, m( $\tilde{t}_1$ )-m( $\chi_1^o$ )= 40 GeV	SUSY-2018-09
		$ ilde{\chi}_1^{\pm}  ilde{\chi}_2^0$ via $WZ$	3 e, μ ee, μμ	$\geq 1$ jet	$E_T^{\rm miss}$ $E_T^{\rm miss}$	139 139	$ \begin{array}{ccc} \tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{2}^{0} & \ \tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{2}^{0} & \ 0.205 \end{array} $		0.64			$m(\tilde{\chi}_1^{\pm})=0$ $m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^{0})=5~\mathrm{GeV}$	ATLAS-CONF-2020-015 1911.12606
		$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp}$ via WW	2 <i>e</i> ,μ	0.1/0	$E_T^{\text{miss}}$	139	$\tilde{\chi}_1^{\pm}$	0.42	0.74			$m(\tilde{\chi}_1^0) = 0$	1908.08215
>	ct	$\chi_1^- \chi_2^\circ$ via $Wh$ $\tilde{\chi}_1^+ \tilde{\chi}_1^+$ via $\tilde{\ell}_L / \tilde{\chi}$	0-1 e,μ 2 e,μ	2 <i>0</i> /2 γ	$E_T^{\text{miss}}$ $E_T^{\text{miss}}$	139 139	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^{\pm}$ Forbidden $\tilde{\chi}_1^{\pm}$		0.74			$m(\tilde{\chi}_1^{*}) = 70 \text{ GeV}$ $m(\tilde{\chi}_1^{*}) = 0.5(m(\tilde{\chi}_1^{*}) + m(\tilde{\chi}_1^{0}))$	1908.08215
Ш	dire	$\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau \tilde{\chi}_1^0$	2 τ		$E_T^{\text{miss}}$	139	$\tilde{\tau}$ [ $\tilde{\tau}_{\mathrm{L}}, \tilde{\tau}_{\mathrm{R,L}}$ ] 0.16	-0.3 0.12-0.39				$m(\tilde{\mathcal{X}}_1^0) = 0$	1911.06660
		$\tilde{\ell}_{\mathrm{L,R}}\tilde{\ell}_{\mathrm{L,R}},\tilde{\ell}{\rightarrow}\ell\tilde{\chi}_{1}^{0}$	2 e, μ ee, μμ	0 jets $\geq 1$ jet	$E_T^{ m miss} \ E_T^{ m miss}$	139 139	${\scriptstyle \widetilde{\ell} \ \widetilde{\ell}}$ 0.256		0.7			$m(\tilde{\chi}_1^0)=0$ $m(\tilde{\ell})-m(\tilde{\chi}_1^0)=10 \text{ GeV}$	1908.08215 1911.12606
		$\tilde{H}\tilde{H},\tilde{H}{ ightarrow}h\tilde{G}/Z\tilde{G}$	0 <i>e</i> , μ 4 <i>e</i> , μ	$\geq 3 b$ 0 jets	$E_T^{ m miss} \ E_T^{ m miss}$	36.1 139	<i>Ĥ</i> 0.13-0.23 <i>Ĥ</i>	0.55	0.29-0.88			$ BR(\tilde{\chi}^0_1 \to h\tilde{G}) = 1 \\ BR(\tilde{\chi}^0_1 \to Z\tilde{G}) = 1 $	1806.04030 ATLAS-CONF-2020-040
lived	cles	$\operatorname{Direct} \tilde{\chi}_1^+ \tilde{\chi}_1^- \text{ prod., long-lived } \tilde{\chi}_1^\pm$	Disapp. trk	1 jet	$E_T^{\rm miss}$	36.1	$egin{array}{ccc}  ilde{\chi}_1^{\pm} & \  ilde{\chi}_1^{\pm} & 0.15 \end{array}$	0.46				Pure Wino Pure higgsino	1712.02118 ATL-PHYS-PUB-2017-019
-bu	arti	Stable $\tilde{g}$ R-hadron		Multiple		36.1	ĝ				2.0		1902.01636,1808.04095
<mark>Po</mark>	ď	Metastable $\tilde{g}$ R-hadron, $\tilde{g} \rightarrow qq \tilde{\chi}_1^0$		Multiple		36.1	$\tilde{g} = [\tau(\tilde{g}) = 10 \text{ ns}, 0.2 \text{ ns}]$				2.05 2.4	$m(\tilde{\chi}_1^0)$ =100 GeV	1710.04901,1808.04095
		$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_1^0 , \tilde{\chi}_1^{\pm} {\rightarrow} Z \ell {\rightarrow} \ell \ell \ell$	3 <i>e</i> , µ			139	$\tilde{\chi}_1^{\mp}/\tilde{\chi}_1^0$ [BR( $Z\tau$ )=1, BR( $Ze$ )=1]	0.	.625 1.05	5		Pure Wino	ATLAS-CONF-2020-009
		$LFV \ pp \to \tilde{\nu}_{\tau} + X, \tilde{\nu}_{\tau} \to e\mu/e\tau/\mu\tau$	<i>еµ,ет,µ</i> τ	0 ioto	rmiss	3.2	$\tilde{\nu}_{\tau}$		0.00	1.00	1.9	$\lambda'_{311}=0.11, \lambda_{132/133/233}=0.07$	1607.08079
		$\chi_1 \chi_1 / \chi_2 \rightarrow W W / Z \ell \ell \ell \ell \nu \nu$ $\tilde{g} \tilde{g} \rightarrow a \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow a a a$	4 e,μ 4	-5 large- <i>R</i> je	ets	36.1	$\chi_1 / \chi_2  [\lambda_{i33} \neq 0, \lambda_{12k} \neq 0]$ $\tilde{g}  [m(\tilde{\chi}^0) = 200 \text{ GeV}, 1100 \text{ GeV}$	/]	0.82	1.33	1.9	$m(\chi_1)=100 \text{ GeV}$ Large $\lambda''_{112}$	1804.03602
20	>	88,8 ,994,1,7,1 ,999		Multiple		36.1	$\tilde{g} = [\lambda_{112}'' = 2e-4, 2e-5]$	1	1.0	5	2.0	$m(\tilde{\chi}_1^0)$ =200 GeV, bino-like	ATLAS-CONF-2018-003
a	č	$t\tilde{t}, t \to t\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to tbs$		Multiple		36.1	$\tilde{t}$ [ $\lambda''_{323}$ =2e-4, 1e-2]	0.55	1.0	5		m $(\tilde{\chi}_1^0)$ =200 GeV, bino-like	ATLAS-CONF-2018-003
		$ \vec{t}\vec{t}, \vec{t} \rightarrow b\chi_1^{\pm}, \chi_1^{\pm} \rightarrow bbs $ $ \vec{t}, \vec{t}, \vec{t}, \rightarrow bs $		$\geq 4b$ 2 jets $\pm 2h$		139 36 7	$\tilde{t}$	Forbidden	0.95			$m(\tilde{\chi}_1^{\pm})$ =500 GeV	ATLAS-CONF-2020-016
		$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	2 <i>e</i> , µ	2 b		36.1	$\tilde{t}_1 = [qq, bs]$ $\tilde{t}_1$	0.42 0		0.4-1.4	15	$BR(\tilde{t}_1 \rightarrow be/b\mu) > 20\%$	1710.05544
		-	1 <i>µ</i>	DV		136	$\tilde{t}_1$ [1e-10< $\lambda'_{23k}$ <1e-8, 3e-10	< $\lambda'_{23k}$ <3e-9]	1.0		1.6	$BR(\tilde{t}_1 \rightarrow q\mu) = 100\%, \cos\theta_t = 1$	2003.11956

\*Only a selection of the available mass limits on new states or phénomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

 $10^{-1}$ 

Mass scale [TeV]

1

ATLAS Preliminary

 $\sqrt{s} = 13 \text{ TeV}$ 

# $E_{ECL}$ clean up in $B \rightarrow D^* \ell v$ Belle II analysis



region of the reconstructed neutral cluster.

FIG. 3. Two versions of  $E_{\text{ECL}}$  are shown: (left) is the version applying detector region dependent energy selection criteria, (right) shows the impact of using a BDT to identify neutral energy depositions from beam background processes. It is based on shower shape variables and the detector