High-Luminosity Energy-Frontier Physics with ATLAS at the Large Hadron Collider

P. Krieger, University of Toronto

(on behalf of the ATLAS Canada Collaboration)

Particle Physics, Nuclear Physics and Beyond, July 13, 2017
TRIUMF Science Week

ATLAS Canada Collaboration

Founded in 1992: M. Lefebvre, UVic
Spokespersons: R.S. Orr U of T 1994–2007
R. McPherson, IPP/UVic 2007-2015

- Alberta
- Carleton
- McGill
- Montréal
- SFU
- Toronto
- TRIUMF
- UBC
- Victoria
- York

Current Management

Spokesperson, PI (2015 –):	P. Krieger, U of T
Deputy:	A. Warburton, McGill
Physics Coord:	A. Lister, UBC
Computing Coord:	D. Gingrich, Alberta

39 University/Lab faculty (~35 FTE)
28 Postdocs, 77 GS (Fall 2016), ≈ 25 UG students/year
Plus engineers and technicians (some MRS funded)
Group includes 5 IPP Research Scientists (4 FTE)

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Com

Faculty complement includes 4 TRIUMF Board Appointed Employees (BAE) as well as 5 TRIUMF RS or TRIUMF/University joint positions at five institutions.

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28 Pc **/year**
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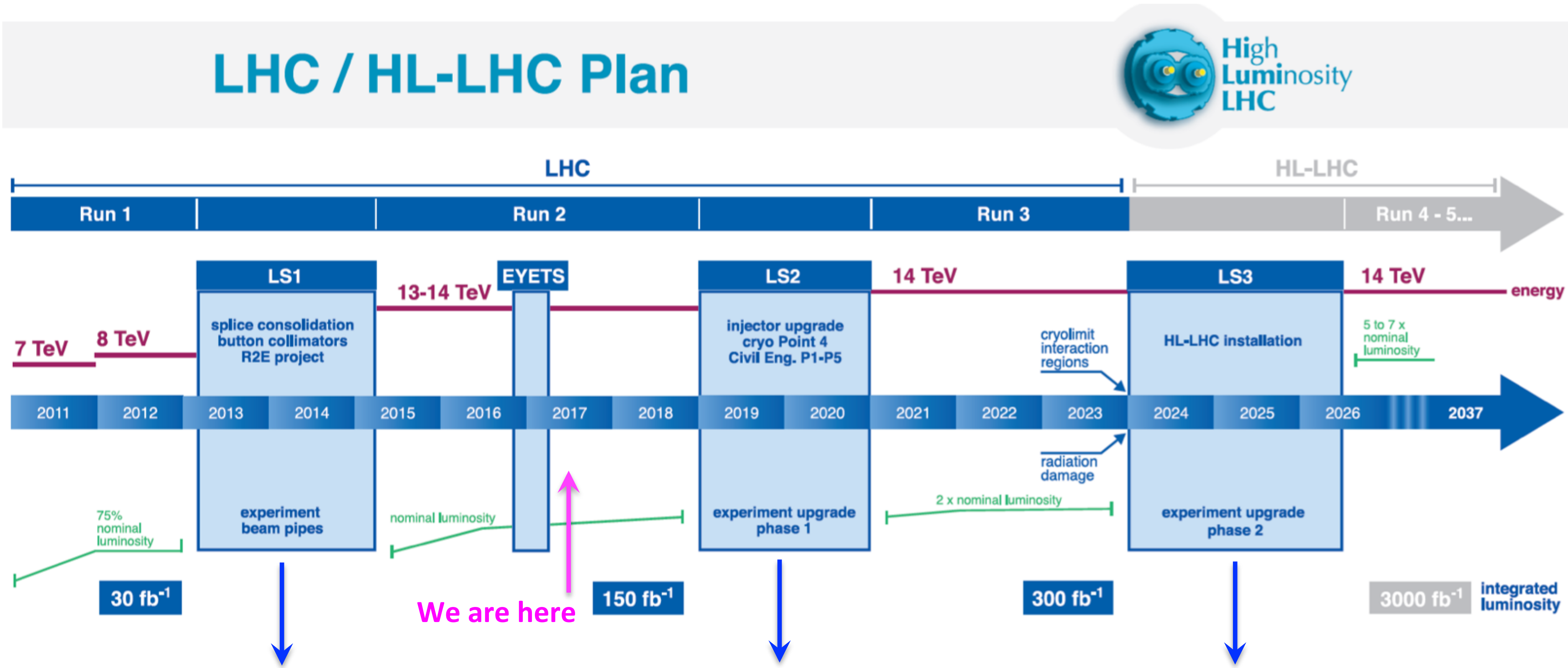
The Large Hadron Collider at CERN

- **The world's highest-energy particle collider**
  - Likely to remain at the energy-frontier for at least another two decades
- **ATLAS: over 645 peer-reviewed papers (published or submitted)**
- **Higgs Boson discovery in 2012 led to 2013 Nobel Prize to Higgs and Englert (with ATLAS and CMS mentioned in the citation)**
  - Investigations of Higgs properties still important and on-going
  - This will remain true to the end of the LHC/HL-LHC experimental program
- **Increased energy, decreased bunch spacing for Run-2 (2015-2018):**
  - Bunch spacing of 25 ns (instead of 50 ns) for reduced pileup
  - 13 TeV up from 8 TeV in Run-1: new window for searches for BSM physics
  - LHC magnet training to 14 TeV investigated during 2016-17 EYETS
  - **Energy will remain at 13 TeV for all of Run-2. Run 3 will be at 14 TeV.**
- **Maximum LHC energy is 14 TeV. After that, planned improvements associated with an increase of the collision rate (luminosity):**
  - The is the goal of both the Phase-I and Phase-II LHC / ATLAS Upgrades

LHC/HL-LHC Schedule / ATLAS upgrade planning



- New Pixel insertable b-layer (IBL): DBM
- Consolidation of LAr calorimeter LVPS
- LUCID upgrade
- Forward protons (AFP)

Completed

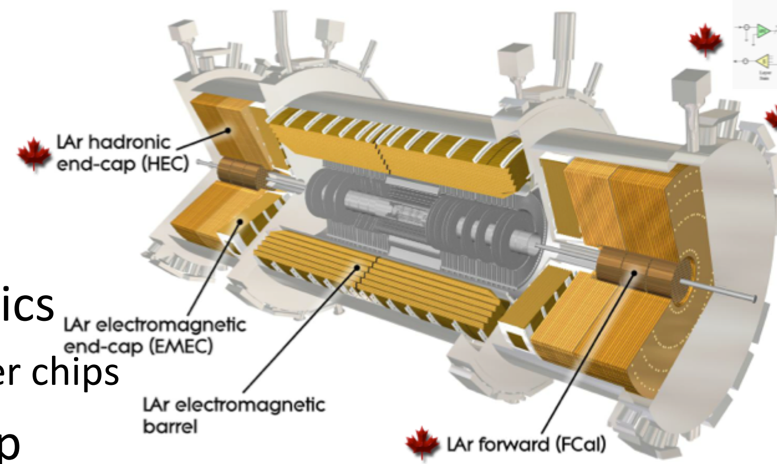
Phase-1 Upgrades

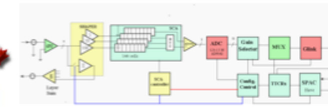
Phase-2 Upgrades

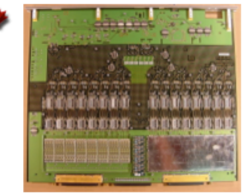
Canadian Hardware Contributions to ATLAS

Main contributions to the original detector

- Hadronic Endcap calorimeter
  - Two of four wheels
- Hadronic Forward calorimeter
  - All four modules
- Liquid argon front-end electronics
  - Switched capacitor array controller chips
- Liquid argon calorimeter endcap signal feedthroughs







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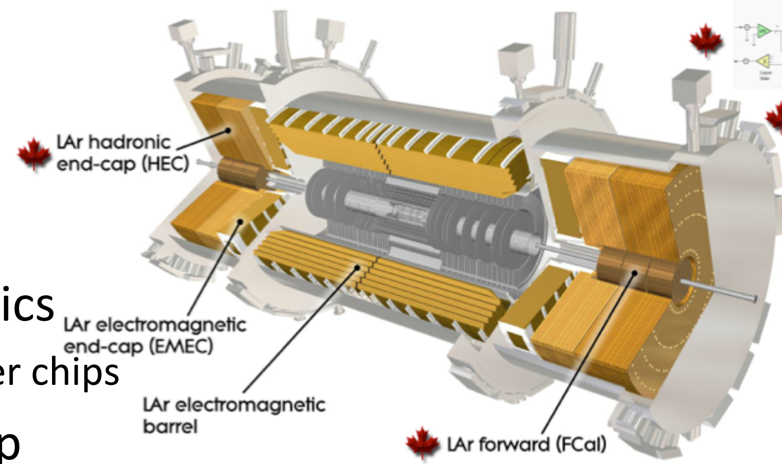

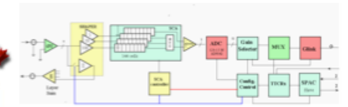

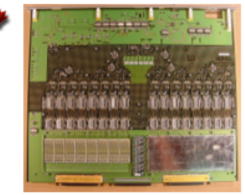

Other contributions to the existing detector

- Diamond Beam Conditions Monitor (also used for luminosity)
- High-level trigger (HLT) processors
- MediPix / TimePix for cavern background monitoring, luminosity
- LUCID luminosity monitor and upgrade in LS1 (2013-2015)
- Diamond Beam Monitor (telescope) installed in LS1 (2013-2015)
- Inner Detector readout
- ATLAS Forward Protons (AFP) – installation completed in 2016/17 shutdown

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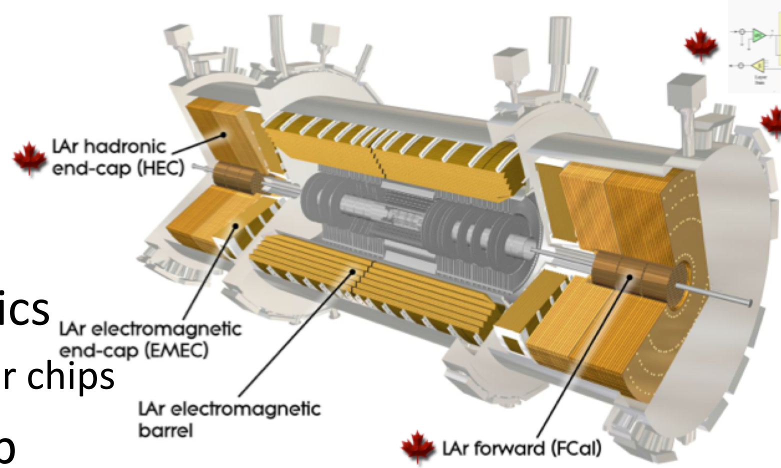

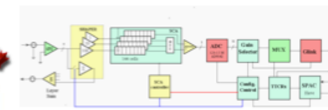

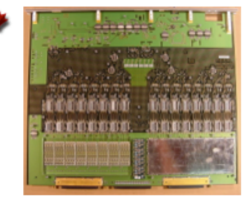

Calorimeter modules and signal feedthroughs will all stay for the HL-LHC

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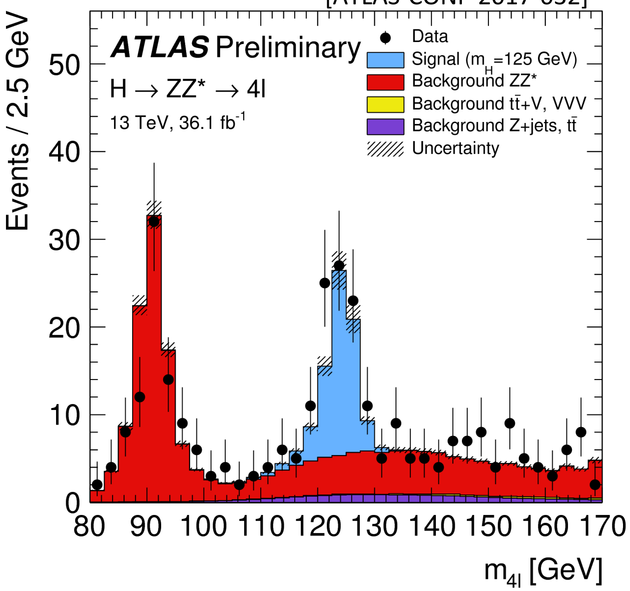
ATLAS Canada Computing

- **Canada also contributes significantly to ATLAS Computing**:
  - CFI-funded Tier-1 facility at TRIUMF
    - Being relocated to SFU in 2017-18 (new hardware)
  - Tier-2 facilities through Compute Canada (CC)
    - These are also evolving as a result of CC site consolidation
- **WLCG MoU commits Canada to providing ATLAS computing resources**:
  - This presumably goes to the end of the nominal LHC experimental program
  - We will be expected to contribute to ATLAS computing in the HL-LHC era
    - The model for this is not yet well understood
    - Community Whitepaper to be delivered in summer 2017:
      - will be used as input to the writing of an HL-LHC computing TDR in 2020
- **TRIUMF remains responsible for Tier-1 operations costs until end of current 5YP in 2020**:
  - Also after that, for salaries, at least for Tier-1 specific tasks
- **Canada also a big player in Cloud Computing** (not only for ATLAS)
  - Could possibly play a more significant role in a future computing model

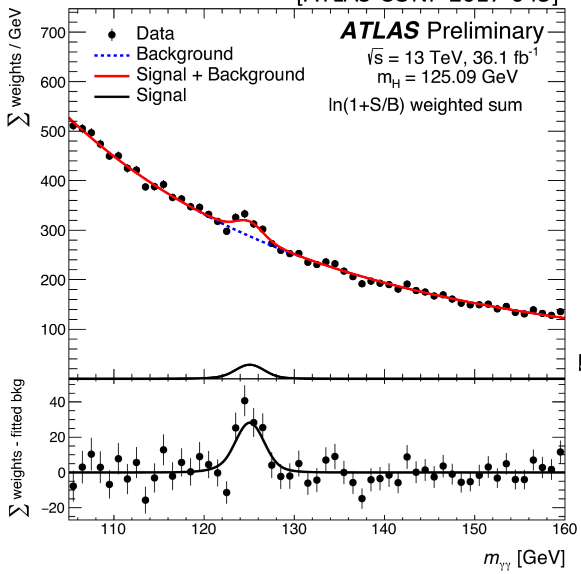
Run-2 Higgs Boson Results

Higgs properties measurements in ZZ^* and diphoton final states

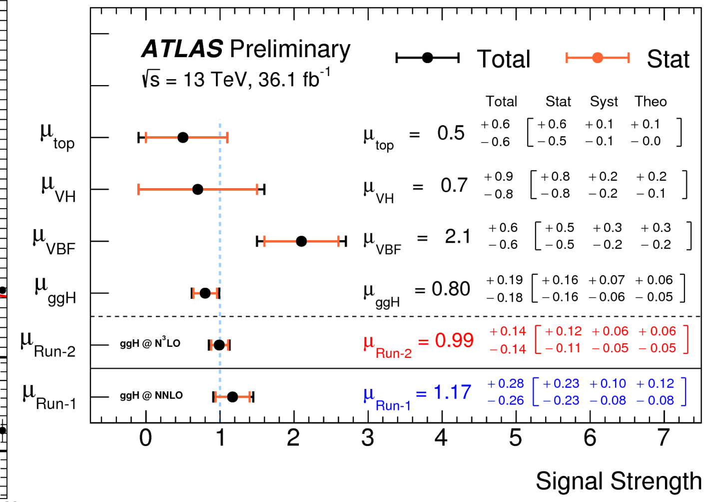
[ATLAS-CONF-2017-032]



[ATLAS-CONF-2017-045]

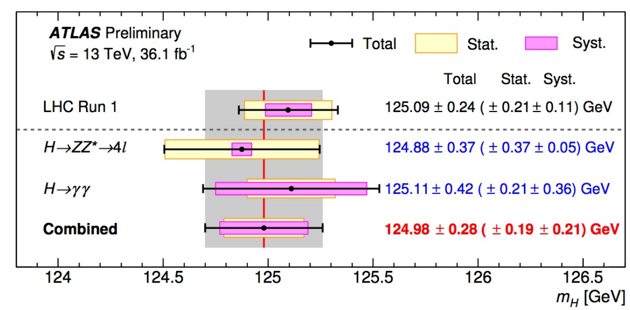


[ATLAS-CONF-2017-045]



Other Run-2 Higgs highlights:

- $ZZ^*/\gamma\gamma$ combined results:
  - Mass [ATLAS-CONF-2017-046]
  - Inclusive cross-sections [ATLAS-CONF-2017-047]
- Differential cross-sections from ZZ^* channel [ATLAS-CONF-2017-032]
- Evidence for Higgs $\rightarrow b\bar{b}$ [ATLAS-CONF-2017-041]



ATLAS SUSY Searches Summary (May 2017)

ATLAS SUSY Searches* - 95% CL Lower Limits

May 2017

ATLAS Preliminary
$\sqrt{s}$ = 7, 8, 13 TeV

$\sqrt{s}$ = 7, 8 TeV | $\sqrt{s}$ = 13 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt [fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e, μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde q, \tilde g$ 1.85 TeV	$m(\tilde q)=m(\tilde g)$	1507.05525
	$\tilde q \tilde q$, $\tilde q \to q \tilde\chi_1^0$	0	2-6 jets	Yes	36.1	$\tilde q$ 1.57 TeV	$m(\tilde\chi_1^0)$<200 GeV, m(1st gen. $\tilde q$)=m(2nd gen. $\tilde q$)	ATLAS-CONF-2017-022
	$\tilde q \tilde q$, $\tilde q \to q \tilde\chi_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde q$ 608 GeV	$m(\tilde q)$-$m(\tilde\chi_1^0)$<5 GeV	1604.07773
	$\tilde g \tilde g$, $\tilde g \to q \bar q \tilde\chi_1^0$	0	2-6 jets	Yes	36.1	$\tilde g$ 2.02 TeV	$m(\tilde\chi_1^0)$<200 GeV	ATLAS-CONF-2017-022
	$\tilde g \tilde g$, $\tilde g \to q q \tilde\chi_1^\pm \to q q W^\pm \tilde\chi_1^0$	0	2-6 jets	Yes	36.1	$\tilde g$ 2.01 TeV	$m(\tilde\chi_1^0)$<200 GeV, $m(\tilde\chi^\pm)$=0.5($m(\tilde\chi_1^0)$+$m(\tilde g)$)	ATLAS-CONF-2017-022
	$\tilde g \tilde g$, $\tilde g \to q q (\ell\ell/\nu\nu) \tilde\chi_1^0$	3 e, μ	4 jets	-	36.1	$\tilde g$ 1.825 TeV	$m(\tilde\chi_1^0)$<400 GeV	ATLAS-CONF-2017-030
	$\tilde g \tilde g$, $\tilde g \to q q W Z \tilde\chi_1^0$	0	7-11 jets	Yes	36.1	$\tilde g$ 1.8 TeV	$m(\tilde\chi_1^0)$ <400 GeV	ATLAS-CONF-2017-033
	GMSB ($\tilde\ell$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	$\tilde g$ 2.0 TeV		1607.05979
	GGM (bino NLSP)	2 γ	-	Yes	3.2	$\tilde g$ 1.65 TeV	$c\tau$(NLSP)<0.1 mm	1606.09150
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde g$ 1.37 TeV	$m(\tilde\chi_1^0)$<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	$\tilde g$ 1.8 TeV	$m(\tilde\chi_1^0)$>680 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2016-066
	GGM (higgsino NLSP)	2 e, μ (Z)	2 jets	Yes	20.3	$\tilde g$ 900 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	$m(\tilde G)>1.8 \times 10^{-4}$ eV, $m(\tilde g)=m(\tilde q)$=1.5 TeV	1502.01518
3rd gen. $\tilde g$ med.	$\tilde g \tilde g$, $\tilde g \to b \bar b \tilde\chi_1^0$	0	3 b	Yes	36.1	$\tilde g$ 1.92 TeV	$m(\tilde\chi_1^0)$<600 GeV	ATLAS-CONF-2017-021
	$\tilde g \tilde g$, $\tilde g \to t \bar t \tilde\chi_1^0$	0-1 e, μ	3 b	Yes	36.1	$\tilde g$ 1.97 TeV	$m(\tilde\chi_1^0)$<200 GeV	ATLAS-CONF-2017-021
	$\tilde g \tilde g$, $\tilde g \to b \bar t \tilde\chi_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde g$ 1.37 TeV	$m(\tilde\chi_1^0)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde b_1 \tilde b_1$, $\tilde b_1 \to b \tilde\chi_1^0$	0	2 b	Yes	36.1	$\tilde b_1$ 950 GeV	$m(\tilde\chi_1^0)$<420 GeV	ATLAS-CONF-2017-038
	$\tilde b_1 \tilde b_1$, $\tilde b_1 \to t \tilde\chi_1^\pm$	2 e, μ (SS)	1 b	Yes	36.1	$\tilde b_1$ 275-700 GeV	$m(\tilde\chi_1^0)$<200 GeV, $m(\tilde\chi_1^\pm)$= $m(\tilde\chi_1^0)$+100 GeV	ATLAS-CONF-2017-030
	$\tilde t_1 \tilde t_1$, $\tilde t_1 \to b \tilde\chi_1^\pm$	0-2 e, μ	1-2 b	Yes	4.7/13.3	$\tilde t_1$ 117-170 GeV; 200-720 GeV	$m(\tilde\chi_1^\pm)$ = 2$m(\tilde\chi_1^0)$, $m(\tilde\chi_1^0)$=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde t_1 \tilde t_1$, $\tilde t_1 \to W b \tilde\chi_1^0$ or $t \tilde\chi_1^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde t_1$ 90-198 GeV; 205-950 GeV	$m(\tilde\chi_1^0)$=1 GeV	1506.08616, ATLAS-CONF-2017-020
	$\tilde t_1 \tilde t_1$, $\tilde t_1 \to c \tilde\chi_1^0$	0	mono-jet	Yes	3.2	$\tilde t_1$ 90-323 GeV	$m(\tilde t_1)$-$m(\tilde\chi_1^0)$=5 GeV	1604.07773
	$\tilde t_1 \tilde t_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde t_1$ 150-600 GeV	$m(\tilde\chi_1^0)$>150 GeV	1403.5222
	$\tilde t_2 \tilde t_2$, $\tilde t_2 \to \tilde t_1 + Z$	3 e, μ (Z)	1 b	Yes	36.1	$\tilde t_2$ 290-790 GeV	$m(\tilde\chi_1^0)$=0 GeV	ATLAS-CONF-2017-019
	$\tilde t_2 \tilde t_2$, $\tilde t_2 \to \tilde t_1 + h$	1-2 e, μ	4 b	Yes	36.1	$\tilde t_2$ 320-880 GeV	$m(\tilde\chi_1^0)$=0 GeV	ATLAS-CONF-2017-019
EW direct	$\tilde\ell_{L,R} \tilde\ell_{L,R}$, $\tilde\ell \to \ell \tilde\chi_1^0$	2 e, μ	0	Yes	36.1	$\tilde\ell$ 90-440 GeV	$m(\tilde\chi_1^0)$=0	ATLAS-CONF-2017-039
	$\tilde\chi_1^+ \tilde\chi_1^-$, $\tilde\chi_1^+ \to \tilde\ell \nu (\ell \tilde\nu)$	2 e, μ	0	Yes	36.1	$\tilde\chi_1^\pm$ 710 GeV	$m(\tilde\chi_1^0)$=0, $m(\tilde\ell, \tilde\nu)$=0.5($m(\tilde\chi_1^\pm)$+$m(\tilde\chi_1^0)$)	ATLAS-CONF-2017-039
	$\tilde\chi_1^\pm \tilde\chi_1^\mp / \tilde\chi_2^0$, $\tilde\chi_1^+ \to \tilde\tau \nu (\tau \tilde\nu)$, $\tilde\chi_2^0 \to \tilde\tau \tau (\nu \tilde\nu)$	2 τ	-	Yes	36.1	$\tilde\chi_1^\pm$ 760 GeV	$m(\tilde\chi_1^0)$=0, $m(\tilde\tau, \tilde\nu)$=0.5($m(\tilde\chi_1^\pm)$+$m(\tilde\chi_1^0)$)	ATLAS-CONF-2017-035
	$\tilde\chi_1^\pm \tilde\chi_2^0 \to \tilde\ell_L \nu \tilde\ell_L \ell (\tilde\nu\nu)$, $\ell \tilde\nu \tilde\ell_L \ell (\tilde\nu \nu)$	3 e, μ	0	Yes	36.1	$\tilde\chi_1^\pm, \tilde\chi_2^0$ 1.16 TeV	$m(\tilde\chi_1^\pm)$=$m(\tilde\chi_2^0)$, $m(\tilde\chi_1^0)$=0, $m(\tilde\ell, \tilde\nu)$=0.5($m(\tilde\chi_1^\pm)$+$m(\tilde\chi_1^0)$)	ATLAS-CONF-2017-039
	$\tilde\chi_1^\pm \tilde\chi_2^0 \to W \tilde\chi_1^0 Z \tilde\chi_1^0$	2-3 e, μ	0-2 jets	Yes	36.1	$\tilde\chi_1^\pm, \tilde\chi_2^0$ 580 GeV	$m(\tilde\chi_1^\pm)$=$m(\tilde\chi_2^0)$, $m(\tilde\chi_1^0)$=0, $\tilde\ell$ decoupled	ATLAS-CONF-2017-039
	$\tilde\chi_1^\pm \tilde\chi_2^0 \to W \tilde\chi_1^0 h \tilde\chi_1^0$, $h \to b\bar b/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde\chi_1^\pm, \tilde\chi_2^0$ 270 GeV	$m(\tilde\chi_1^\pm)$=$m(\tilde\chi_2^0)$, $m(\tilde\chi_1^0)$=0, $\tilde\ell$ decoupled	1501.07110
	$\tilde\chi_2^0 \tilde\chi_3^0$, $\tilde\chi_{2,3}^0 \to \tilde\ell_R \ell$	4 e, μ	0	Yes	20.3	$\tilde\chi_{2,3}^0$ 635 GeV	$m(\tilde\chi_2^0)$=$m(\tilde\chi_3^0)$, $m(\tilde\chi_1^0)$=0, $m(\tilde\ell, \tilde\nu)$=0.5($m(\tilde\chi_2^0)$+$m(\tilde\chi_1^0)$)	1405.5086
	GGM (wino NLSP) weak prod., $\tilde\chi_1^0 \to \gamma \tilde G$	1 e, μ + γ	-	Yes	20.3	$\tilde W$ 115-370 GeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod., $\tilde\chi_1^0 \to \gamma \tilde G$	2 γ	-	Yes	20.3	$\tilde W$ 590 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde\chi_1^+ \tilde\chi_1^-$ prod., long-lived $\tilde\chi_1^\pm$	Disapp. trk	1 jet	Yes	36.1	$\tilde\chi_1^\pm$ 430 GeV	$m(\tilde\chi_1^\pm)$-$m(\tilde\chi_1^0)$~160 MeV, $\tau(\tilde\chi_1^\pm)$=0.2 ns	ATLAS-CONF-2017-017
	Direct $\tilde\chi_1^+ \tilde\chi_1^-$ prod., long-lived $\tilde\chi_1^\pm$	dE/dx trk	-	Yes	18.4	$\tilde\chi_1^\pm$ 495 GeV	$m(\tilde\chi_1^\pm)$-$m(\tilde\chi_1^0)$~160 MeV, $\tau(\tilde\chi_1^\pm)$<15 ns	1506.05332
	Stable, stopped $\tilde g$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde g$ 850 GeV	$m(\tilde\chi_1^0)$=100 GeV, 10 μs<$\tau(\tilde g)$<1000 s	1310.6584
	Stable $\tilde g$ R-hadron	trk	-	-	3.2	$\tilde g$ 1.58 TeV		1606.05129
	Metastable $\tilde g$ R-hadron	dE/dx trk	-	-	3.2	$\tilde g$ 1.57 TeV	$m(\tilde\chi_1^0)$=100 GeV, τ>10 ns	1604.04520
	GMSB, stable $\tilde\tau$, $\tilde\chi_1^0 \to \tilde\tau(\tilde e, \tilde\mu) + \tau(e, \mu)$	1-2 μ	-	-	19.1	$\tilde\chi_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde\chi_1^0 \to \gamma \tilde G$, long-lived $\tilde\chi_1^0$	2 γ	-	Yes	20.3	$\tilde\chi_1^0$ 440 GeV	1<$\tau(\tilde\chi_1^0)$<3 ns, SPS8 model	1409.5542
	$\tilde g \tilde g$, $\tilde\chi_1^0 \to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde\chi_1^0$ 1.0 TeV	7 <$c\tau(\tilde\chi_1^0)$< 740 mm, $m(\tilde g)$=1.3 TeV	1504.05162
	GGM $\tilde g \tilde g$, $\tilde\chi_1^0 \to Z \tilde G$	displ. vtx + jets	-	-	20.3	$\tilde\chi_1^0$ 1.0 TeV	6 <$c\tau(\tilde\chi_1^0)$< 480 mm, $m(\tilde g)$=1.1 TeV	1504.05162
RPV	LFV $pp \to \tilde\nu_\tau + X$, $\tilde\nu_\tau \to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	3.2	$\tilde\nu_\tau$ 1.9 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde q, \tilde g$ 1.45 TeV	$m(\tilde q)=m(\tilde g)$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde\chi_1^+ \tilde\chi_1^-$, $\tilde\chi_1^+ \to W \tilde\chi_1^0$, $\tilde\chi_1^0 \to ee\nu, e\mu\nu, \mu\mu\nu$	4 e, μ	-	Yes	13.3	$\tilde\chi_1^\pm$ 1.14 TeV	$m(\tilde\chi_1^0)$>400GeV, $\lambda_{12k} \neq 0$ ($k = 1, 2$)	ATLAS-CONF-2016-075
	$\tilde\chi_1^+ \tilde\chi_1^-$, $\tilde\chi_1^+ \to W \tilde\chi_1^0$, $\tilde\chi_1^0 \to \tau\tau\nu_e, e\tau\nu_\tau$	3 e, μ + τ	-	Yes	20.3	$\tilde\chi_1^\pm$ 450 GeV	$m(\tilde\chi_1^0)$>0.2×$m(\tilde\chi_1^\pm)$, $\lambda_{133} \neq 0$	1405.5086
	$\tilde g \tilde g$, $\tilde g \to qqq$	0	4-5 large-R jets	-	14.8	$\tilde g$ 1.08 TeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde g \tilde g$, $\tilde g \to qq \tilde\chi_1^0$, $\tilde\chi_1^0 \to qqq$	0	4-5 large-R jets	-	14.8	$\tilde g$ 1.55 TeV	$m(\tilde\chi_1^0)$=800 GeV	ATLAS-CONF-2016-057
	$\tilde g \tilde g$, $\tilde g \to t \bar t \tilde\chi_1^0$, $\tilde\chi_1^0 \to qqq$	1 e, μ	8-10 jets/0-4 b	-	36.1	$\tilde g$ 2.1 TeV	$m(\tilde\chi_1^0)$= 1 TeV, $\lambda_{112} \neq 0$	ATLAS-CONF-2017-013
	$\tilde g \tilde g$, $\tilde g \to \tilde t_1 t$, $\tilde t_1 \to bs$	1 e, μ	8-10 jets/0-4 b	-	36.1	$\tilde g$ 1.65 TeV	$m(\tilde t_1)$= 1 TeV, $\lambda_{323} \neq 0$	ATLAS-CONF-2017-013
	$\tilde t_1 \tilde t_1$, $\tilde t_1 \to bs$	0	2 jets + 2 b	-	15.4	$\tilde t_1$ 410 GeV; 450-510 GeV		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde t_1 \tilde t_1$, $\tilde t_1 \to b\ell$	2 e, μ	2 b	-	36.1	$\tilde t_1$ 0.4-1.45 TeV	BR($\tilde t_1 \to be/\mu$)>20%	ATLAS-CONF-2017-036
Other	Scalar charm, $\tilde c \to c \tilde\chi_1^0$	0	2 c	Yes	20.3	$\tilde c$ 510 GeV	$m(\tilde\chi_1^0)$<200 GeV	1501.01325

10^{-1} 1 **Mass scale [TeV]**

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

ATLAS Exotics Searches Summary July 2017

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\,dt = (3.2 - 37.0)\ \text{fb}^{-1}$ $\sqrt{s}$ = 8, 13 TeV

	Model	ℓ,γ	Jets†	E_T^{miss}	$\int\mathcal{L}\,dt[\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK}+g/q$	0 e,μ	1 – 4 j	Yes	36.1	M_D 7.75 TeV	$n=2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n=3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n=6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e,μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n=6$, $M_D=3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n=6$, $M_D=3$ TeV, rot BH	1512.02586
	RS1 $G_{KK}\to\gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl}=0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK}\to WW\to qq\ell\nu$	1 e,μ	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl}=1.0$	ATLAS-CONF-2017-051
	2UED / RPP	1 e,μ	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)}\to tt)=1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z'\to\ell\ell$	2 e,μ	–	–	36.1	Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z'\to\tau\tau$	2 τ	–	–	36.1	Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z'\to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z'\to tt$	1 e,μ	≥ 1 b, ≥ 1J/2j	Yes	3.2	Z' mass 2.0 TeV	$\Gamma/m=3\%$	ATLAS-CONF-2016-014
	SSM $W'\to\ell\nu$	1 e,μ	–	Yes	36.1	W' mass 5.1 TeV		1706.04786
	HVT $V'\to WW\to qqqq$ model B	0 e,μ	2 J	–	36.7	V' mass 3.5 TeV	$g_V=3$	CERN-EP-2017-147
	HVT $V'\to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V=3$	ATLAS-CONF-2017-055
	LRSM $W'_R\to tb$	1 e,μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R\to tb$	0 e,μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η_{LL}^-		1703.09217
	CI $\ell\ell qq$	2 e,μ	–	–	36.1	Λ 40.1 TeV η_{LL}^-		ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/≥ 3 e,μ	≥ 1 b, ≥ 1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR}\rvert=1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e,μ	1 – 4 j	Yes	36.1	m_{med} 1.5 TeV	g_q=0.25, g_χ=1.0, $m(\chi)<400$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	0 e,μ, 1 γ	≤ 1 j	Yes	36.1	m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi)<480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	0 e,μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi)<150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta=1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta=1$	1605.06035
	Scalar LQ 3rd gen	1 e,μ	≥ 1 b, ≥ 3 j	Yes	20.3	LQ mass 640 GeV	$\beta=0$	1508.04735
Heavy quarks	VLQ $TT\to Ht+X$	0 or 1 e,μ	≥ 2 b, ≥ 3 j	Yes	13.2	T mass 1.2 TeV	$\mathcal{B}(T\to Ht)=1$	ATLAS-CONF-2016-104
	VLQ $TT\to Zt+X$	1 e,μ	≥ 1 b, ≥ 3 j	Yes	36.1	T mass 1.16 TeV	$\mathcal{B}(T\to Zt)=1$	1705.10751
	VLQ $TT\to Wb+X$	1 e,μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	T mass 1.35 TeV	$\mathcal{B}(T\to Wb)=1$	CERN-EP-2017-094
	VLQ $BB\to Hb+X$	1 e,μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 700 GeV	$\mathcal{B}(B\to Hb)=1$	1505.04306
	VLQ $BB\to Zb+X$	2/≥ 3 e,μ	≥ 2/≥ 1 b	–	20.3	B mass 790 GeV	$\mathcal{B}(B\to Zb)=1$	1409.5500
	VLQ $BB\to Wt+X$	1 e,μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	B mass 1.25 TeV	$\mathcal{B}(B\to Wt)=1$	CERN-EP-2017-094
	VLQ $QQ\to WqWq$	1 e,μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^*\to qg$	–	2 j	–	37.0	q^* mass 6.0 TeV	only u^* and d^*, $\Lambda=m(q^*)$	1703.09127
	Excited quark $q^*\to q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda=m(q^*)$	CERN-EP-2017-148
	Excited quark $b^*\to bg$	–	1 b, 1 j	–	13.3	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^*\to Wt$	1 or 2 e,μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g=f_L=f_R=1$	1510.02664
	Excited lepton ℓ^*	3 e,μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda=3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e,μ,τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda=1.6$ TeV	1411.2921
Other	LRSM Majorana ν	2 e,μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R)=2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm}\to\ell\ell$	2,3,4 e,μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm}\to\ell\tau$	3 e,μ,τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm}\to\ell\tau)=1$	1411.2921
	Monotop (non-res prod)	1 e,μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{non-res}=0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert=5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert=1g_D$, spin 1/2	1509.08059

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

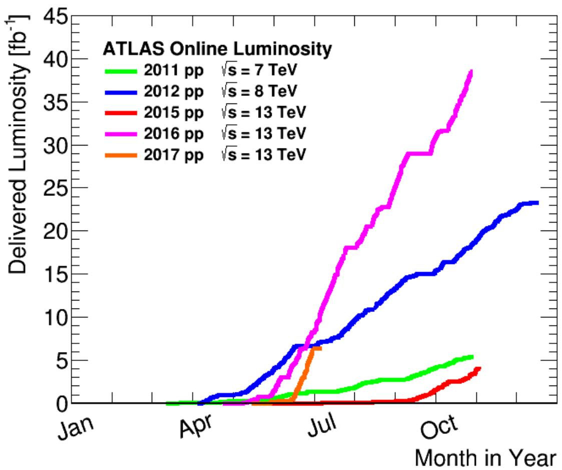
Mass scale [TeV]: 10^{-1}, 1, 10

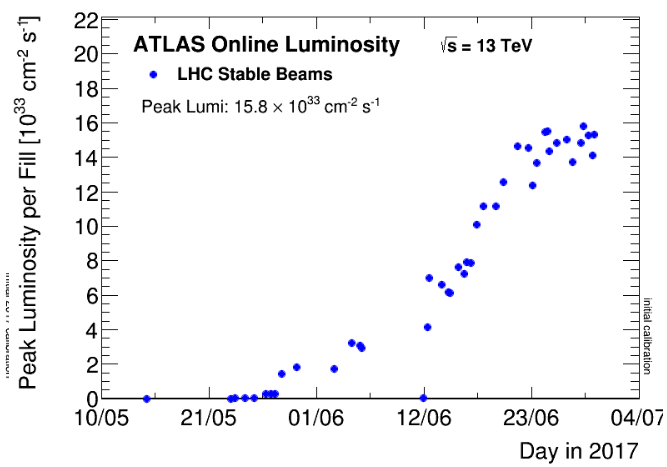
*Only a selection of the available mass limits on new states or phenomena is shown.

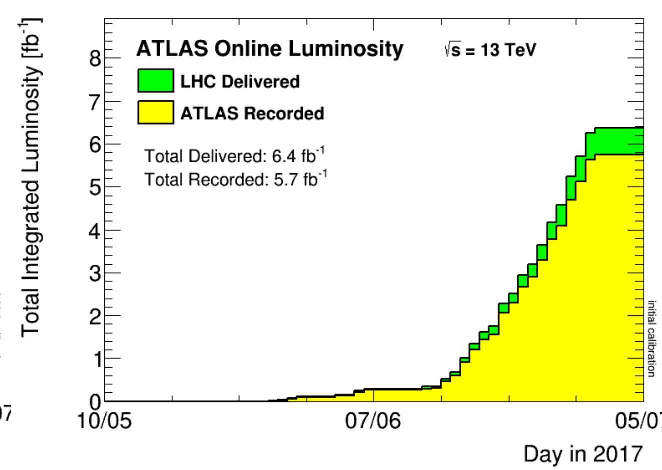
†Small-radius (large-radius) jets are denoted by the letter j (J).

Current Status (2017 Running)

- **First stable beams (3 x 3 bunches) declared May 23**
- **Steady luminosity ramp: slope currently exceeds that of 2016**
  - Reached nominal number of bunches for 2017 running: 2556
  - Achieved new record instantaneous luminosity of 1.6 x 10^{34} $cm^{-2}s^{-1}$
  - Discussions in progress on increasing to 2.2 x 10^{34} $cm^{-2}s^{-1}$
    - Would require leveling or trigger adaptations at start of run
- **Summary: the machine is performing excellently**
- **ATLAS performing very well: efficiency currently > 90% and increasing**







HEP Planning Exercises

- **Canadian community recently went through NSERC-supported LRP exercise: report published in 2016**
- **Canadian Fundamental Science Review ("Naylor report") 2017:**
  - Did not specifically address HEP, but supportive of international collaboration
  - Lobbying effort (for implementation of the recommendations) underway
- **European Strategy for Particle Physics: next update is due in May 2020, so around the start of the next TRIUMF 5YP**
  - CERN already organizing process for input:
    - Kickoff meeting for workshop on HL-LHC physics in Oct 30 − Nov 1, 2017
    - Will include studies for the HE-LHC (28 TeV)
    - Process to culminate in CERN Yellow Report by end 2018; to be provided as input into European Strategy discussion.
- **2017 update of American (P5) priorities:**
  - HL-LHC, LBNF, DUNE, + existing construction projects
- **Longer-term international planning and investigations for:**
  - Linear electron-positron colliders
  - Large circular colliders for electron-positron or hadron-hadron collisions (or both)
  - Physics program discussed in previous talk: more on this later on (but briefly)

NSERC Subatomic Physics Long Range Plan

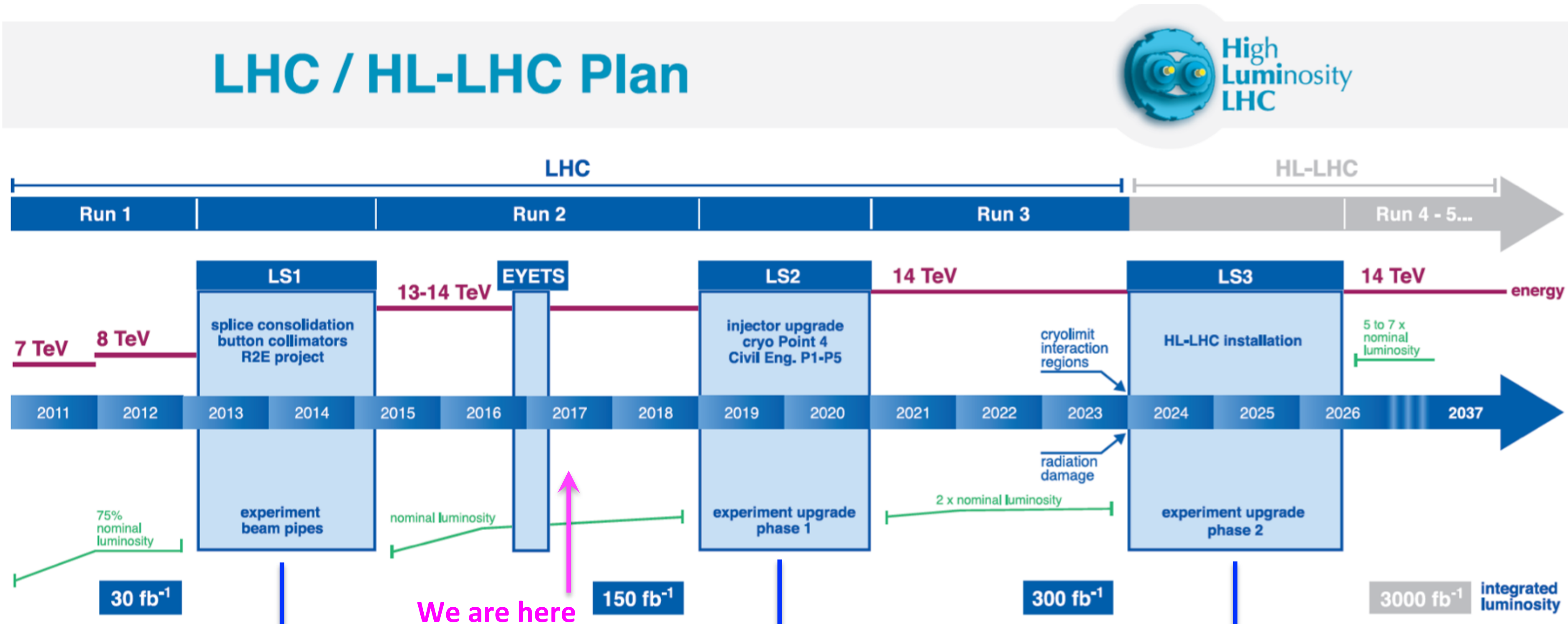
Recommendations of LRP

A number of major international facilities and experiments that will further the understanding of the universe will become operational in the coming years. It is important for Canada to engage in such projects to maintain vitality in the field. Furthermore, it is crucial to become active in early stages so that Canadians may take on leadership roles and to ensure success of the projects.

SCIENTIFIC RECOMMENDATION:

Position Canada for key leadership roles in strategic projects and initiatives by supporting activities in potential future flagship endeavours. Those projects with significant Canadian participation should continue to receive support: ATLAS at the High-Luminosity LHC, Belle II, Hyper-Kamiokande, ILD at ILC, MOLLER and SoLID at JLab, nEXO at SNOLAB, and UCN/nEDM at TRIUMF.

LHC/HL-LHC Schedule / ATLAS upgrade planning



- New Pixel insertable b-layer (IBL): DBM
- Consolidation of LAr calorimeter LVPS
- LUCID upgrade
- Forward protons (AFP)

Completed

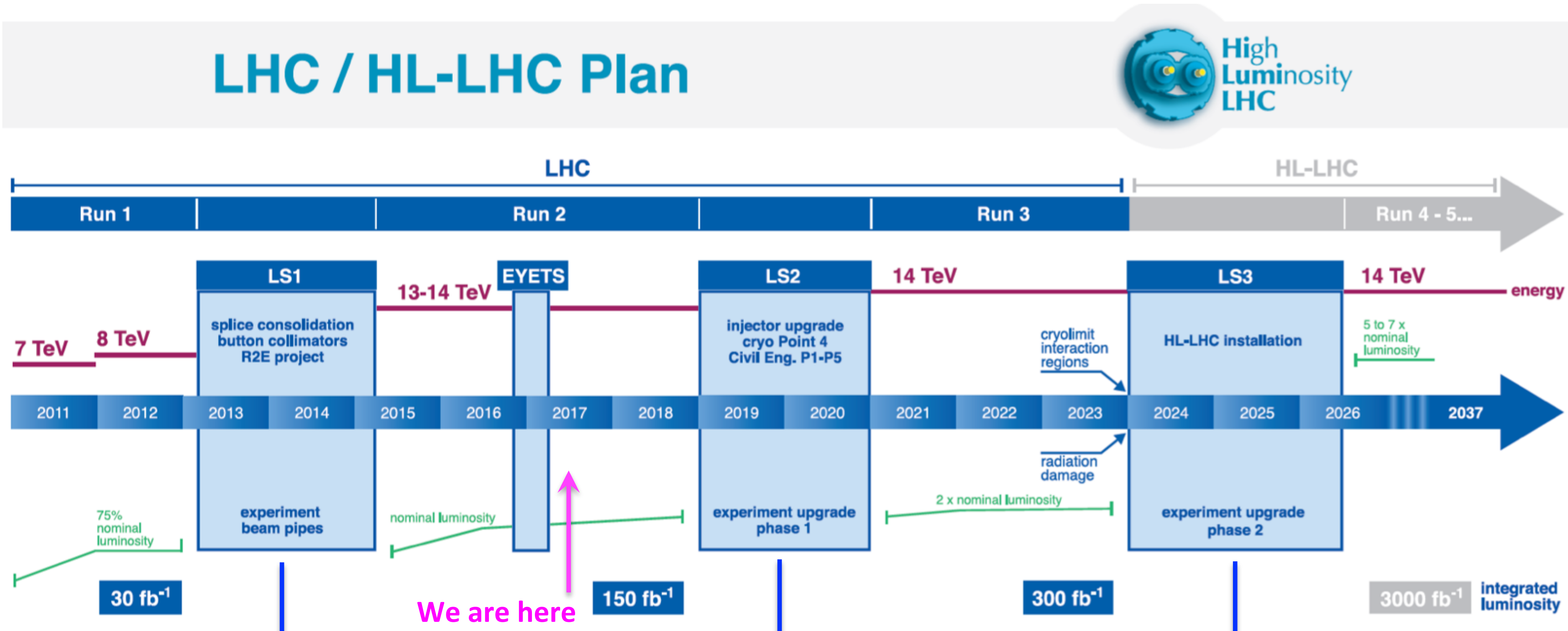
Phase-1 Upgrades

Phase-2 Upgrades

2020-2025

Operations
Analysis / Publication
Phase-1 Upgrades (installation / commissioning)
Phase-2 Upgrades (construction)

LHC/HL-LHC Schedule / ATLAS upgrade planning



- New Pixel insertable b-layer (IBL): DBM
- Consolidation of LAr calorimeter LVPS
- LUCID upgrade
- Forward protons (AFP)

Completed

- sTGC for Muon New Small Wheel
- Liquid Argon Calorimeter electronics

In progress

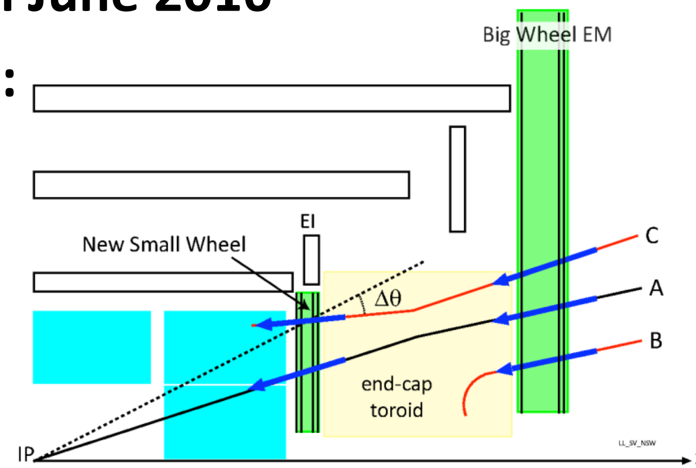
- New ATLAS Inner Tracker (ITk)
- LAr Calorimeter electronics

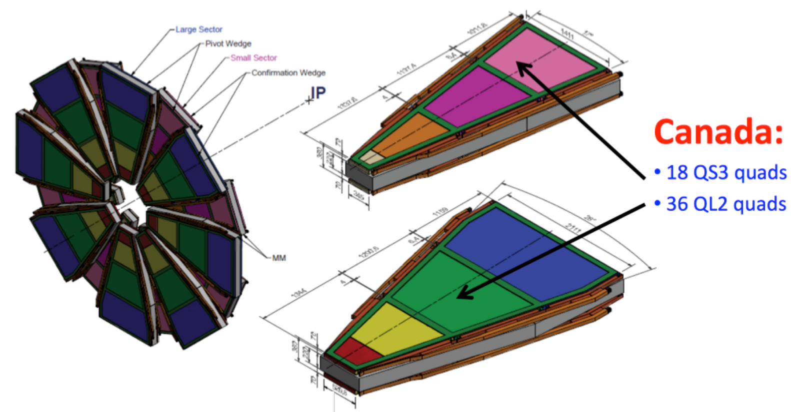
Currently still in R&D Phase
ITk Strips TDR approved, June 2017
LAr TDR planned for Fall 2017

TRIUMF Involved in all ATLAS Canada upgrade projects

Phase-1 Upgrades: Muon New Small Wheel

- **NSW key component of ATLAS trigger strategy for Run-3 (fake rejection)**
- **sTGC construction/testing infrastructure at TRIUMF, Carleton and McGill**
- **Module-0 sTGC completed by Canadian group in May 2016**
- **Production Readiness Review (PRR) passed in June 2016**
- **Leading coordination roles in NSW project:**
  - Overall project management, schedule, finances
  - Cathode board procurement / preparation
  - Wedge assembly at CERN
  - Software / simulation
  - Electronics / software for cosmic-ray test station
  - Production test pulser board for sTGCs

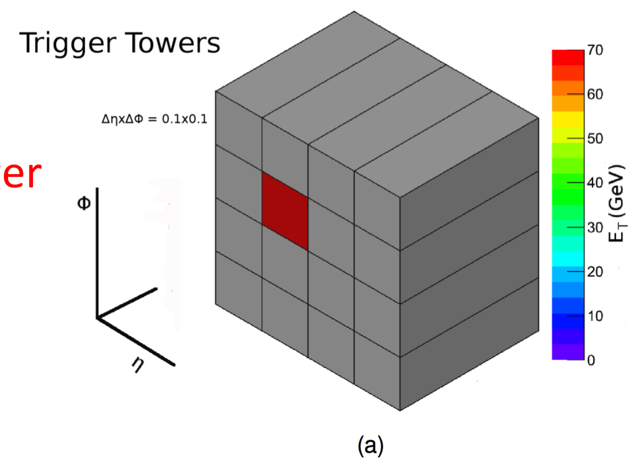


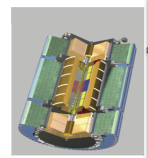


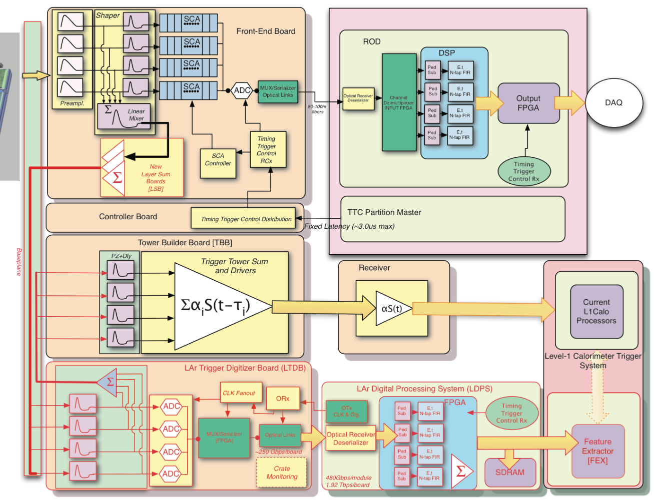
Phase-1 Upgrades: LAr Calorimeter Electronics

- **Another key component of ATLAS trigger strategy for Run-3**
- **Improve granularity of information supplied to the L1 trigger**
  - Provide additional background (fakes) suppression at trigger level

Current trigger granularity







Phase-1 Upgrades: LAr Calorimeter Electronics

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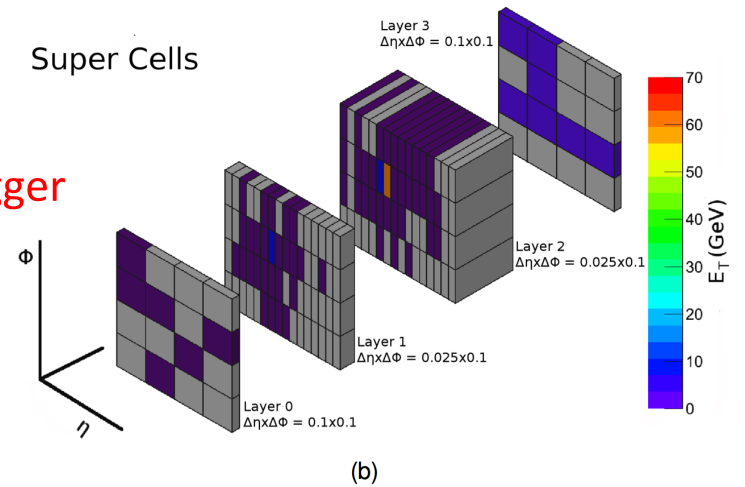
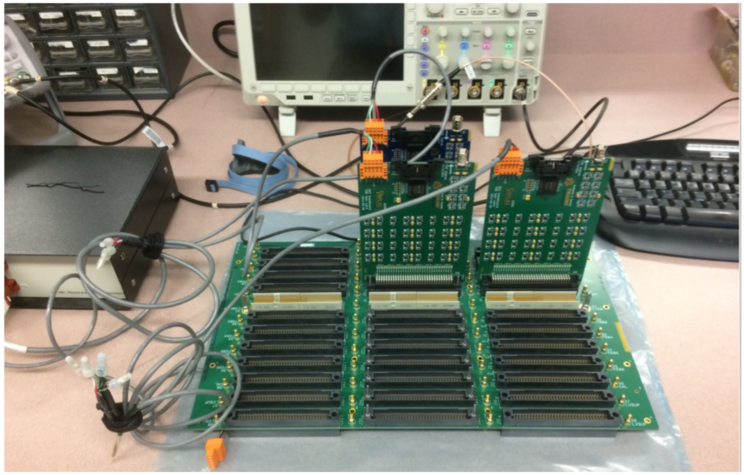
Phase-1 trigger granularity





- **Implementation requires new Front-End Crate baseplanes**
  - Canada: design, production & testing of new HEC baseplanes
- **Design, prototyping and assembly at TRIUMF**
- **Acceptance testing at the University of Victoria**

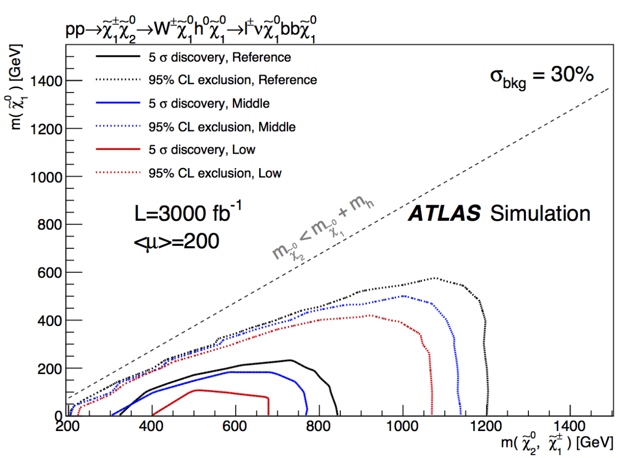
ATLAS at the High Luminosity LHC

- **Proposed instantaneous luminosity of 7.5×10^{34} $cm^{-2}s^{-1}$ ($\mu \approx 200$)**
  - Needed for the targeted (×10) increase in integrated luminosity (3000 fb^{-1})
  - Rate and accumulated dose causes problems for some detector subsystems
  - Need for pileup suppression becomes crucial issue for detector upgrades
- **Proposed L0/L1 trigger scheme with rates of 1MHz/400KHz is incompatible with both tracker and calorimeter readout electronics:**
  - Calorimeters modules can operate but:
    - Forward calorimeter response will be somewhat degraded at high $|\eta|$
    - **Calorimeter front- and back-end electronics must be entirely replaced**
- **Radiation dose and occupancy also an issue for the tracker**
  - **This will be entirely replaced by a new all-silicon tracker, the ITk**
    - Pixels at low radius, strips at higher radius.
      - Coverage out to $|\eta| = 4.0$ (from 2.5 for current inner tracker)
    - 160 m^2 of silicon. Almost half the cost / effort of Phase-II upgrades

- **Phase-2 upgrades to Muon system also planned**
- **Forward Si timing detector also being considered**

Phase-II Upgrades: Physics Motivations

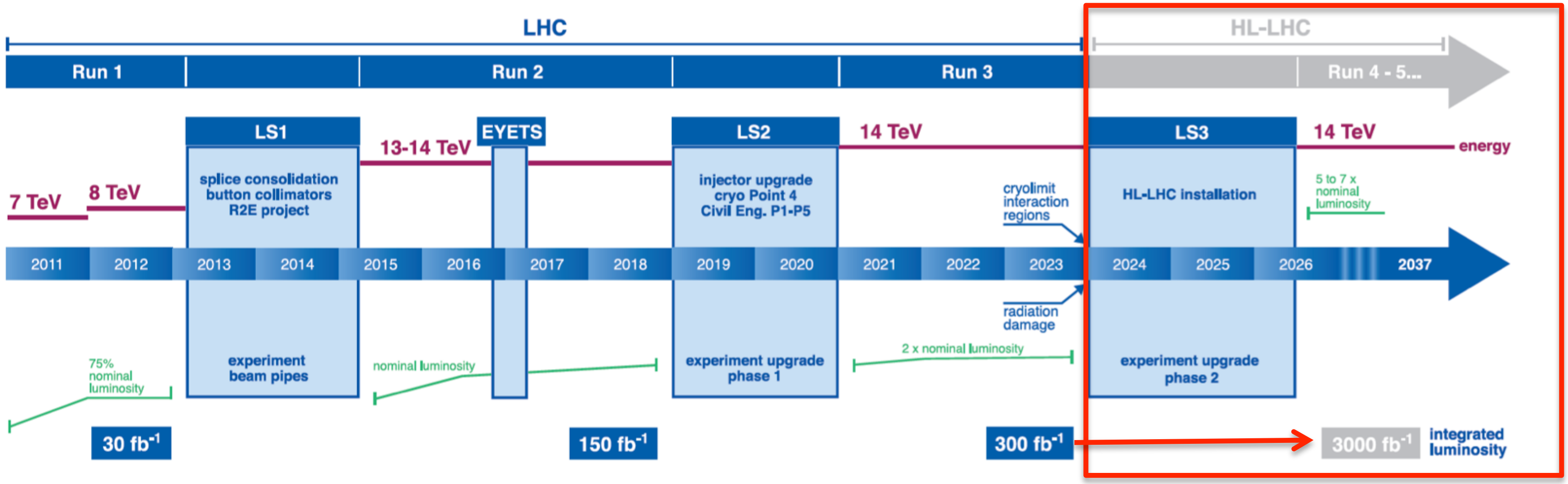
- **Primary goals: discovery of BSM and more detailed studies of the Higgs boson**
- **Higgs studies, in particular couplings:**
  - Improvements over results with 300 fb^{-1}
  - Access to second-generation fermion couplings via $H \rightarrow \mu\mu$
  - Investigations of Higgs self coupling (via HH production)
  - Vector boson scattering: is this Higgs alone responsible for unitarizing $\sigma\left(V_L V_L \rightarrow V_L V_L\right)$
    - Sensitivity to VBF/VBS drives performance requirements in forward region
- **Searches: increased sensitivity to rare SM/BSM processes**
  - Exploration of Run-3 hints observations or discoveries.
  - Or (better?) the unexpected



Detector system	Trigger–DAQ		Inner Tracker	Inner Tracker + Muon Spectrometer	Inner Tracker + Calorimeter		
	Efficiency/ Thresholds						
Object Performance / Physics Process	$\mu^{\pm}$	$e^{\pm}$	b-tagging	$\mu^{\pm}$ Identification/ Resolution	Pile-up rejection	Jets	E_T^{miss}
$H \longrightarrow 4\mu$	✓			✓			
VBF $H \rightarrow ZZ^{(*)} \rightarrow \ell\ell\ell\ell$	✓	✓		✓	✓	✓	
VBF $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	✓	✓	✓	✓	✓	✓	✓
SM VBS ssWW	✓	✓		✓	✓	✓	✓
SUSY, $\chi_1^{\pm}\chi_2^{o} \rightarrow \ell b\bar{b} + X$	✓	✓	✓	✓	✓	✓	✓
BSM $HH \rightarrow b\bar{b}b\bar{b}$			✓			✓	

[LHCC-G-166: physics processes for Phase-II performance studies]

The High-Luminosity LHC (HL-LHC)



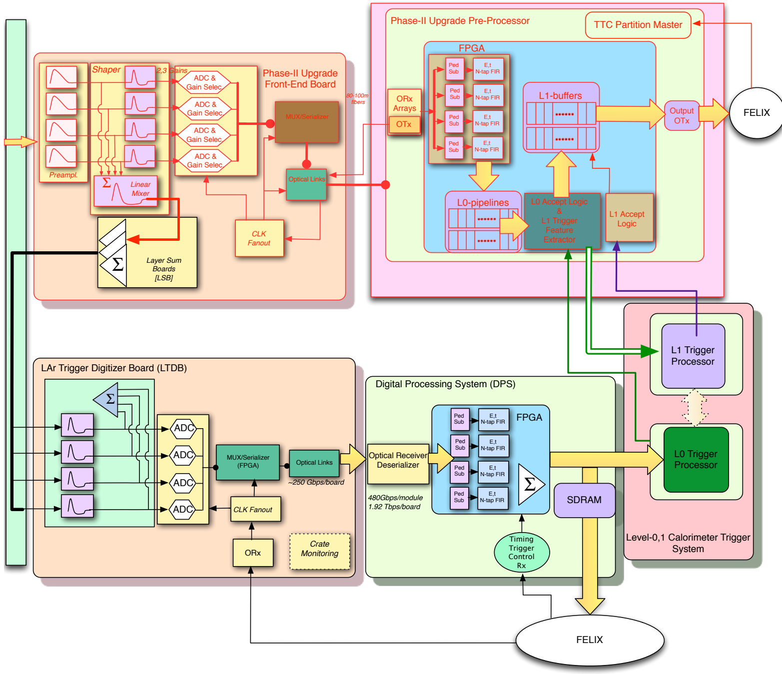
- Formally approved by CERN Council in June 2016
- Highest priority future project for European and U.S. particle physics communities
- High priority of Canadian subatomic physics community
- Significant **detector challenges** in this environment with up to 200 separate proton-proton collisions per bunch-crossing (“pileup”)

90% of the data to be produced by the LHC will be come during the HL-LHC phase

Liquid Argon Calorimeter Electronics Upgrade

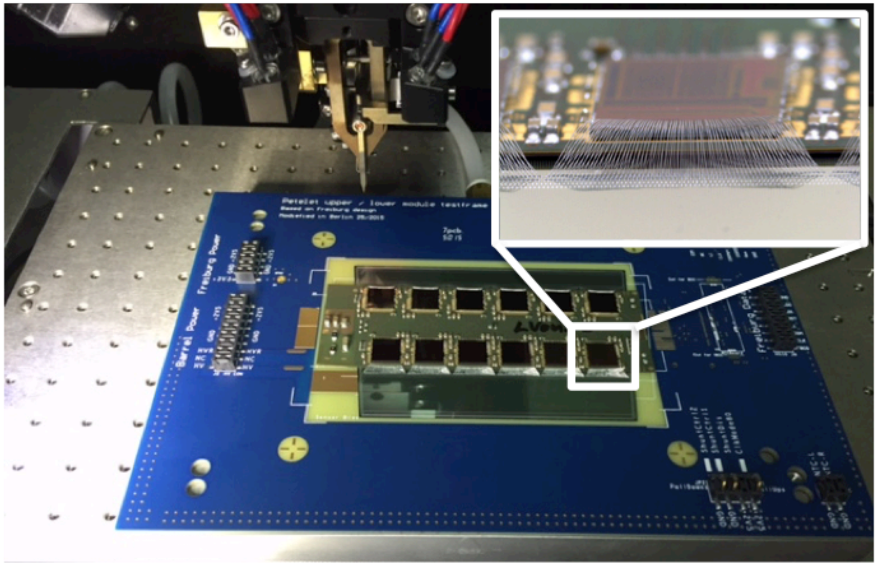
LAr Calorimeter electronics: Front-End (FE), Back-End(BE)

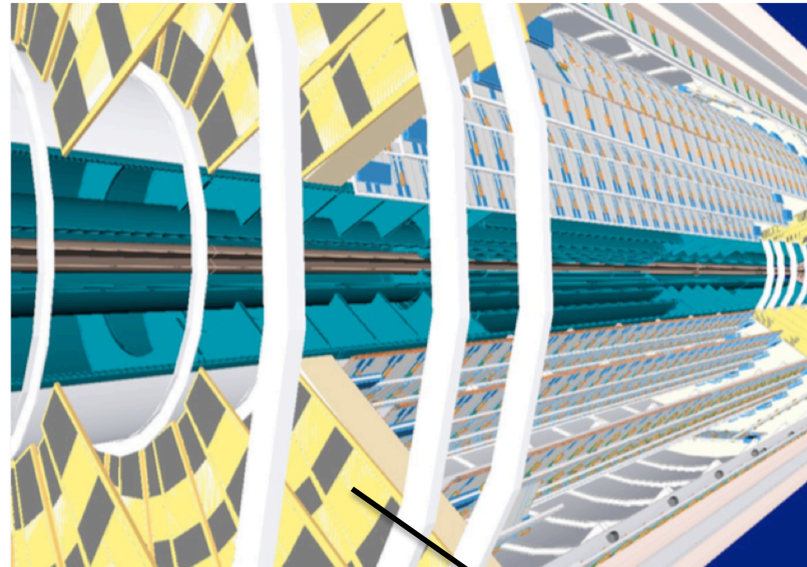
- **On-detector front-end readout electronics must be entirely replaced:**
  - Existing FE electronics would not survive radiation dose at the HL-LHC, and are incompatible with Phase-II trigger scheme (data-taking rate)
  - Trigger electronics already being upgraded in LS2. Will remain for HL-LHC
- **Replacement of FE system requires replacement of BE system**
- **Readout of Hadronic Endcap Calorimeter (HEC) is special:**
  - Canadians have particular expertise here
- **Planned Canadian contributions to:**
  - The design and testing of the new electronics with a focus on the HEC FE
  - BE signal processing techniques
  - Manufacture and installation of new of FE and BE electronics



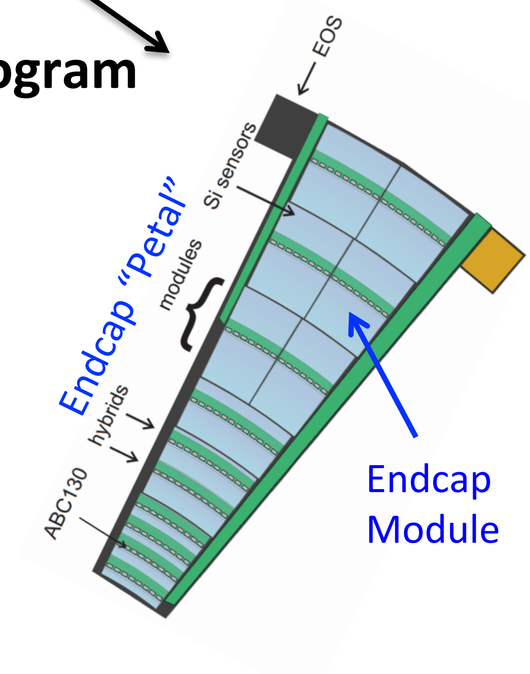
[Victoria, TRIUMF, McGill]

Phase-II Tracker Upgrade (ITk)



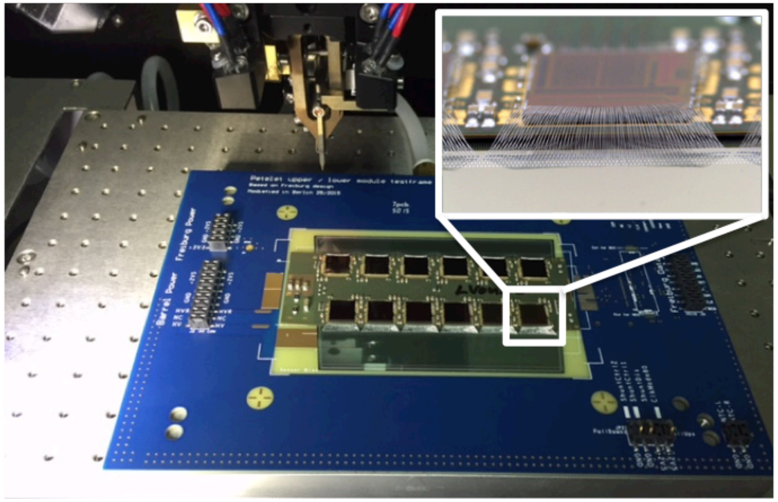


- **Excellent tracking needed for the HL-LHC physics program**
  - Need precision vertexing to identify the primary vertex to which hard-scatter products are associated (pileup suppression)
- **New tracker (ITk) will have pixels closest to the interaction point, and Si-strip detectors beyond this**
  - **18k Si-strip modules needed in total / 7000 in endcaps**
- **Canadian group proposing to construct 20% of the full Endcap Strips detector (modules, "petals")**
  - **1500 Si strip modules ≈ 83 petals**



Phase-II Tracker Upgrade (ITk)

- **Sophisticated wire-bonding required: ~50 wire-bonder years needed**
  - Requires many sites



- **Two Canadian production / testing sites:**
  - West (TRIUMF, UBC, SFU)
  - East (Toronto, Carleton, York, Montreal)
- **Module production:**
  - Mainly industrial in the East (Celestica)
  - “in house” in the West:
    - TRIUMF has invested in necessary infrastructure (+ SFU JELF)
    - also 2016 TRIUMF hire of silicon detector expert
- **Beyond module production**
  - Industrial production of “hybrid” boards (first stage of readout) [eastern site]
  - Si strip detector acceptance testing [both sites]
  - Industrial probing / dicing of ASIC wafers for hybrid boards [eastern site, industry]
  - Precision placement of modules onto support structure [western site]
  - DAQ development

ATLAS Canada Operations & Upgrade Funding

- **Operations: currently in final year of three-year NSERC project grant**
  - We will continue to request operating support from NSERC
- **Phase-1 Upgrades**
  - LAr, NSW projects currently under construction, funded by CFI IF 2015 award
  - Significant initial R&D support from NSERC in 2013, 2014
  - Support from TRIUMF (beyond that funded by CFI)
- **Phase-2 Upgrades**
  - NSERC RTI awards in 2016 and 2017 for R&D phase
  - Toronto OCE-VP1 for R&D work with Celestica
  - SFU JELF for Si detector infrastructure − matching from TRIUMF
  - Construction funding requested from CFI in IF 2017 competition:
    - Multi-institutional: all ATLAS-Canada institutions provided CFI envelope share
    - LAr Electronics, ITk, Upgrade Common Fund
    - Decision known but not public yet.
- **Computing**
  - IF 2017 proposal for Tier-1 hardware refresh: decision know but not public

TRIUMF 5YP 2020-25 and Beyond

- **ATLAS Canada activities from 2020-2025:**
  - Completion of Run-2 data analysis (data taking ends at end of 2018)
  - Installation (2019-2020) and commissioning (2021) of Phase-1 upgrades
  - Run-3 operations, analysis, publications
  - Construction & Installation of Phase-2 upgrade contributions
    - Work needs to begin before 2020 but extends through to 2025
    - Support from TRIUMF needed for these projects
    - TRIUMF Review of Phase-2 upgrade projects in fall 2016 (prior to CFI submission)
      - Formal Gate-2 review still to take place
    - Funds requested for TRIUMF-based manpower in CFI request
      - Increased following review, at the request of the review committee
  - Will need to define contributions to ATLAS Computing in HL-LHC era
- **ATLAS Canada activities from 2025-2035:**
  - Completion of Run-3 data analysis
  - Installation / commissioning of HL-LHC + ATLAS detector upgrades
  - ATLAS Canada computing for HL-LHC era

HL-LHC Planning / Luminosity Profile

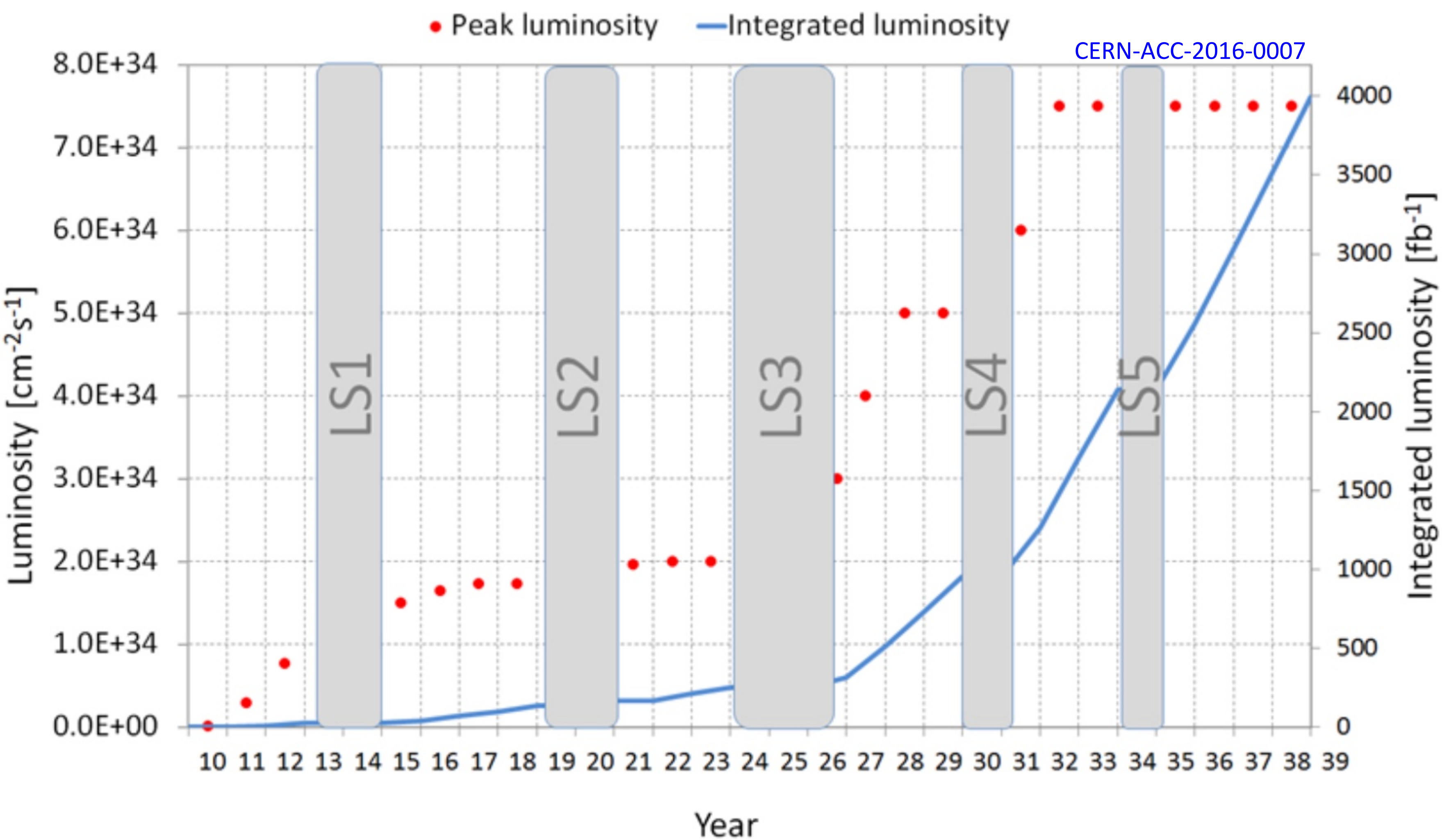


Figure 7: Evolution of peak and integrated luminosity along the LHC and HL-LHC lifetime. The goal of 3000 fb^{-1} might be overcome and 4000 or more fb^{-1} can be reached before year 2040.

Canadian Contributions to the HL-LHC

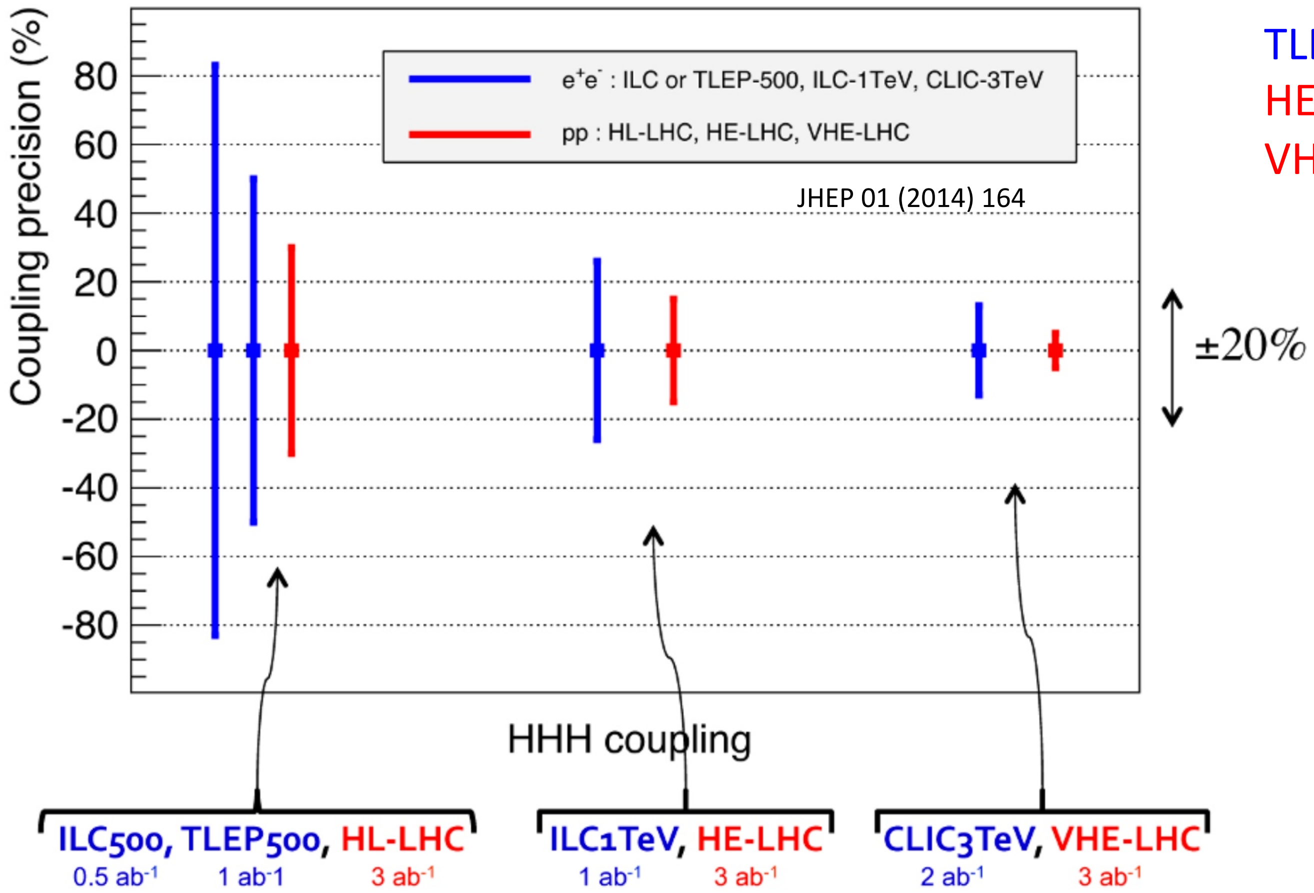
- **CERN has requested that we contribute to the HL-LHC accelerator upgrade**
  - Canada made significant contributions to the LHC construction (~$40M)
    - Warm quadrupole magnets, pulse-forming networks for injection kickers, other beamline work, and beam-dynamics simulation studies
    - These projects were performed or overseen by TRIUMF personnel
  - New contributions will need community support and involvement of TRIUMF
    - Discussions re-starting: needs to converge in time for the 2018 federal budget
    - CERN DG Fabiola Gianotti will be at ICFA meeting in Ottawa in November
- **Initial request from CERN was for replacement warm quadrupole magnets**
    - One of the original Canadian contributions to the LHC
    - CERN has since determined that the radiation damage is not as severe as expected
    - New request is for a contribution to the crab cavities (CC)
- **Accelerator division in discussion with CERN about CC contributions**
- **TRIUMF already working on some HL-LHC beam-beam studies**
- **This is *independent* of discussions related to possible CERN Associate Membership for Canada (which is a longer-term issue)**

Beyond 2030

- **The HL-LHC scheduled to operate until late 2030s**
- **International community already thinking about what comes after this:**
  - HE-LHC: re-use LHC tunnel for higher energy pp machine
    - 16 T dipole magnets to double collision energy (28 TeV)
    - 11 T Nb_3Sn dipoles already under development for HL-LHC
  - Linear e^+e^- Collider:
    - ILC ($\sqrt{s}$ up to 1 TeV)
    - CLIC ($\sqrt{s}$ up to 3 TeV)

    } (Linear Collider Collaboration (LCC) encompasses both)
  - Future Circular Collider (80-100 km circumference) :
    - FCC: ee, hh, eh options (Europe)
    - CEPC (ee) proposal in China: can also be upgraded to pp machine in later stage
- **Canada will clearly want to be involved in this physics program**:
  - Canadian strategy has long been to maximize impact by focusing effort
  - Also would plan to contribute to accelerator R&D and construction:
    - These contributions would presumably again be pursued via TRIUMF

Beyond 2030: Higgs Self-Coupling Sensitivity



TLEP = FCC ee
HE-LHC = 28 TeV LHC
VH-LHC = FCC hh

Future accelerators can operate as both Higgs and top factories

BSM physics program will depend on results from LHC / HL-LHC

Summary

- **For the 2020-25 period of the next TRIUMF 5YP:**
  - Canadian contributions to ATLAS operation & upgrades well defined
  - Canadian contributions to the accelerator upgrade program under discussion
- **TRIUMF playing a key role in all Canadian ATLAS upgrade projects**
  - For both Phase-1 and Phase-2
  - And of course in ongoing ATLAS operations and physics studies
  - Canadian accelerator contributions will need to be managed through TRIUMF
- **The future of ATLAS-Canada computing in the HL-LHC era is not yet well defined, but Canada will need to contribute:**
  - Currently TRIUMF plays an important role in ATLAS-Canada computing
  - Expect that we will need to submit a future funding proposal for HL-LHC era ATLAS computing contributions sometime in 2020-2025
- **Canadian community will want to contribute to next generation collider experiments:**
  - Accelerator contributions would be expected to go through TRIUMF
    - This of course will require broad support of the Canadian community