Summary and Closeout

Alberto Escalante del Valle

4th Workshop of the LLP Community, Amsterdam.

25th October 2018
**CERN** @CERN · 3h

🎉 Today at 6 a.m. protons said their goodbyes to the LHC during a last lap of the track. It was the LHC's last proton run from now until 2021.

**ATLAS Experiment** @ATLASexperiment · 9h

Today marks the last day of proton-proton collisions for Run 2 of the LHC! In total, ATLAS has recorded 149 fb⁻¹ of data at 13 TeV – a huge dataset for physicists to study the Standard Model and probe for hidden signatures.

**CMS Experiment CERN** @CMSexperiment · 2h

Last proton beams of Run 2 were dumped today at 6AM, marking the end of a very successful data taking period. The LHC delivered 66 fb⁻¹ of collisions in 2018 and CMS operations teams managed to achieve almost 95% data taking efficiency in an extraordinary effort. Congratulations!

**LHCb Experiment** @LHCbExperiment

Today marks the end of an era! We have finished detecting proton-proton collisions with the "classic" LHCb detector, after exciting and fruitful 9 years of data taking. Thanks LHC !!

After the lead-lead collisions in November, we will prepare the newly upgraded LHCb detector.
Run # Closeout

→ Higgs is more SM-line (and more) ✓
   What about the other old big questions?
   and new ones?

++ Neutrino masses? ✓ mass and origin, Majorana or Dirac, additional species X
++ Dark Matter? 4/5; Composition, only gravitational? X
++ m_H natural or fine tuned? elementary?, is it alone?, Portal to NP? X

... Insert your favorite Q here X
Exotics?  "Who ordered that?"

→ the muon was discovered.

→ in modern language: "A long-lived HSCP"

→ "the top is special", "it does not hadronize..."

→ "Dark QCD can be more complex than expected"

LLPs look exotic only because our detectors are not optimized for them.

[Nature does not care about this...]

... and they provide answers to the old/new questions.

Thanks: B. Shuve, 2017 CERN LLP Workshop
We are already doing the most complicated/expensive LHC is our main LLP factory ($\sim$ 2040)

Road to discovery

- Upgrades
- New experiments
- 0(10) talks

- Dedicated triggers
- 0(5) talks

- RECORD

- DETECT

- Search

- Theory input
- Community input 0(15), 0(10), 0(5)
- New tools/techniques
- $+$ $+$ 0(10) Discussion blocks

"Leave no stone unturned"

"Goal of this workshop and LHC-LLP Community"

[we don't want to be the generation that "produced" BSM]
**LHC Detector Upgrades**

- The long-lived particle community is having a very positive impact in the design of the future LHC detectors!

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**PHASE #**: 

- **ATLAS**
  - CMS
  - LHCb (Run #)

  **-> ATLAS pixel becomes bigger. Will this affect disappear track searches (??) !!!!**

  **TIMING:**

  - **CMS**
    - LYSO:Ce crystals with SiPM (Barrel), \(O(cm^2)\) channels
    - LGAD Silicon sensors (Endcaps), \(O(mm^2)\) channels
      - 30-40 ps per tracks.
      - Coverage \(\eta < 3\)
  - **ATLAS**
    - LGAD Silicon sensors , \(O(mm^2)\) channels
      - 30 ps per tracks.
      - Coverage \(2.4 < \eta < 4\)

  **Input FROM LLP Community !!!!**

  - While some LLP benchmarks are being considered in these documents, I encourage the LLP community to focus some of their creative energy on these future pp colliders & detectors

  **-> Huge potential of timing for LLP's**

  **LHCb**: (Run #)

  - New software-based “trigger” with offline-quality
    - Profit from capabilities of triggering displaced vertices and possibility of more sophisticated algorithm at trigger-level

  **Huge potential for new searches!!**

  **ex: \(Z \rightarrow e\mu\)**
Record LLPs on tape: • A key point for Run 3 will be to **trigger** on what we may have missed!

→ LLPs need dedicated **Triggers**

New ideas: Turbo / Scouting

**Motivation:** Study B anomalies. Can be used also for LLP search.

**Goal:** Collect large (~10^{10} events) unbiased sample of B

**Idea:** Triggering on muon from B (tag), to collect unbiased B on the other side (probe)

In Run III (LHCb): "Offline-quality" trigger.

In Run IV (ATLAS/CMS): Tracker information to the trigger / Possibly timing too. (CMS)

→ For theorist: "Please always ask your LLP friend if their signal can be triggered"

→ My favorite: "LLP Models that we do not trigger on today... But we could in Run III/Run IV"
def Brainstorming():
    ++ New models // signatures // holes in coverage
    ++ Input beyond the LHC
    ++ New analysis methods (ML...)

while "LLP search" != Discovery:
    Coffee ++
    go to Brainstorming()
Input beyond the LHC: Dark Photons

Belle II: Also capable of displaced search (ongoing studies)

Complementarity with LHC MET searches?
Beyond minimal models

- $A, Z, Z_0$

New signatures

Displaced?

Models beyond Higgs decay?
Light dark Higgs?

Outside lepton-jet regime
HNL's

Right Handed Neutrino Mass Scale

- eV
- keV
- MeV
- GeV
- TeV
- $10^{14}$ GeV

Neutrino Physics
- LSND etc
- Neutrino Cosmology
- Dark Radiation
- Dark Matter
- Origin of Matter
- "Seesaw Mechanism"
- "Leptogenesis"

Direct Searches
Indirect Searches

Challenges in a displaced HNL ATLAS search:

- Beyond minimal \( \nu \) MSM: 3HNL
- Interesting for leptogenesis
- Gauge extensions: TeV (\( W, Z, HNLs \))

Q: Also LLP's?
- New searches?

\[ \tau_{N_e} = (4.15 \times 10^{-12} \text{ s}) (M_N/1 \text{ GeV})^{-5.17} |U|^{-2} \]
\[ \tau_{N_{\mu}} = (4.49 \times 10^{-12} \text{ s}) (M_N/1 \text{ GeV})^{-5.19} |U|^{-2} \]
\[ \tau_{N_{\tau}} = (1.08 \times 10^{-11} \text{ s}) (M_N/1 \text{ GeV})^{-5.44} |U|^{-2} \]

- Use this parametrisation for HNL masses above 4 GeV
  - Model dependence?
  - Factor 2 discrepancy due to LFV decay modes??
  - The community should agree on a model

- Example of filter for HNL search (dominant muon mixing):
  - Single-muon trigger and combined muon with \( p_T > 28 \text{ GeV} \)
  - \(~35\%\) signal efficiency, from trigger acceptance and \( p_T \) threshold

\[ \rightarrow \text{LHCb also a main actor in B/D decays.} \]
Emerging jets

First search at the LHC:

- LHCb for low mediator mass?
  - Improvements with ML?
  - Displaced vertex reconstruction?

LHCb opportunities

- $Z'$ mediator is difficult to trigger at ATLAS/CMS
  - Same if dominant production is off-shell

- Reconstruct individual dark pions, differentiate using lifetime, mass, decay products

- Emerging jets without (hard) trigger requirements?

- Vary dark force parameters to see effects on showers and sensitivity, e.g.:
  - Different $N_C, N_F$
  - Dark pion multiplicity enhanced for $\Lambda_d \sim m_{\pi_d}$
  - More fragmentation for $\Lambda_d > m_{\pi_d}$

Upgrades in LHCb/ATLAS/CMS will boost the sensitivity for EJ scenarios. Don't we have projections with EJ scenarios? Definitely an area with room for improvement!
New in this 4th Edition ... and Very promising!! Analogy with images \{ jets ... \}

Analogy with images \{ hits ... \}

Low mass dark-photon

Dark-shower: "non-QCD-like tagging"

40% better dark photon ID

Jets from QCD multijet

Jets from \( \gamma \) bremsstrahlung

NN Output

LO muon trigger \( \chi_{ip} \)

Low level input for the NN: hit patterns in the Muon Spectrometer RPC chambers

Today's presentation

LO muon trigger based on CNN to be implemented on FPGA @HL-LHC
- Pointing and non-pointing muons reconstruction
- Decay vertex reconstruction of long lived neutral particles decaying in two muons

\[ L = L_{Auto} - \lambda L_{Adv} \]

Counteract with adversary:

Q: Non QCD-like = LLP-like?

\( \rightarrow \) From HF-taggers to LLP-taggers

Important: Validation, Calibration, Control regions to train...

\( \rightarrow \) Territory almost unexplored in LLPs
HSCPs’s

"Who ordered that"?!

☑ Anita - LLP - LHC Connection

→ 500 GeV τ̄ as explanation of anomalous events.

Can we talk about the 510 ± 160 GeV CMS event? Reinterpretation

ATLAS Gluino

Q: Can we improve HSCP searches with the new timing detectors?

Q: Extensions to other models / lifetime dimension.
New theory ideas

ATLAS/CMS

Mixed LLP signatures? (i.e. DT+DV)

→ Possible with theory motivation ...
   but interesting if it helps triggering.

New tools?

→ LLP to heavy flavor tagger
→ Displaced tau tagger

Realm of LHCb

Dark shower signal with light/soft dark hadrons

decay hadronically within ~ m distance

LHCb

New signature: Exclusive searches on LLP decays

Why not in LHCb, ATLAS/CMS?

→ Input for detector upgrades

Discriminate Dark QCD models?
Q: Where are the LLP searches involving taus?

ex: Low mass $Z' \rightarrow ZZ; Z' \rightarrow \mu \nu ...$

Challenging searches!
"We don't want to be the generation that "produced" BSM"

* What if my LLP is:
  - Too light
  - Too Long-Lived
  - Mili-charged
  - A monopole

→ Dedicated LLP experiments at the LHC
Dedicated LLP experiments all over the ring

In LHCb

In CMS

In ATLAS/CMS/LHCb

FASER/ MATHUSLA/Codex-b

In Alice

(called “AL3X” and pronounced “Alex”)

AL3X (New)
**A game of Backgrounds**

Zero background near IP

Background already ~0 without exploiting the tracker!

**Goal is a background-free MATHUSLA!**

First background measurements // Calibrations with demonstrators ...

**FASER**

- First results promising - consistent with FLUKA

**CODEX-b**

- Ongoing work on the LHCb side
  - Background data analysis
  - Detector design and simulation
  - On track for a detector paper in Spring 2019

**MATHUSLA**

Angle distribution for downward particles

Angle distribution for upward particles

- Cumulative hits vs lumi per lumi section

**In-situ charge calibration**

- Scale by path length ratio \( \rightarrow N_{PE} \)
  \( Q = 1 \) \( \rightarrow \sim 80 \) (through-going muon)
- Scale by \( Q^2 \) for low charge \( \rightarrow N_{PE} = 1 \) for \( Q \sim 0.003 \)

- Consistent with result from GEANT4 simulation!
Optimization of $p$ (size, reach): Input from the community welcome!

How does it compare with CMS/ATLAS/LHCb exploiting full improvements i.e. timing information, Trigger improvements...

New AL2X

Br($D_s \rightarrow \chi_1^0 + X$)Br($\chi_1^0 \rightarrow \text{visibles}$)
Executive Summary

Max[P (discovery | LLP produced at the LHC)]

One question arose:

How do we best ensure that we don't miss BSM LLP signatures for the remainder of the LHC program and beyond?

Scary: Where do we look?

Freedom: Everywhere! We have one of the most sophisticated devices ever built at our disposal, and our job is to push it to its limits, to map out all available experimental object space.

This means bold new ideas involving LLPs. 2018 is the perfect time to be bold!

This graph shows the integrated luminosity delivered to the ATLAS and CMS experiments during different LHC runs. The 2018 run produced 65 inverse femtobarns of data, which is 16 points more than in 2017. (Image: CERN)
Dank u zeer!

#LLP2018 ORGANISATION

Community organisers (lhc-llp-coordination@cern.ch)

- LHCb: Carlos Vázquez Sierra, Elena Dall’Occo (Nikhef),
- ATLAS: James Beacham (Duke U.), Ryu Sawada (U. Tokyo),
- CMS: Steven Lowette (VUB), Alberto Escalante del Valle (HEPHY),
- Theory: José Zurita (KIT), Pedro Schwaller (U. Mainz).

Local organisers (llp2018-nikhef@cern.ch)

- Joan Berger (Nikhef - secretary),
- Igor Kostiuk (Nikhef),
- Elena Dall’Occo (Nikhef),
- Wouter Hulsbergen (Nikhef),
- Marcel Merk (Nikhef),
- Carlos Vázquez Sierra (Nikhef).
Until 2021

PROTON PHYSICS: BEAM DUMP

Energy: 6499 GeV  \( I(B1): \ 1.64e+09 \)  \( I(B2): \ 3.83e+08 \)

Search for long-lived particles at the LHC:
Fourth workshop of the LHC LLP Community
23-25 October 2018
Nikhef, Amsterdam
indico.cern.ch/e/LHC LLP October 2018

@ 14 TeV

Until 2019

5th workshop of the LLP Community