# List of SMARTHEP participants

Academic beneficiaries:

- **Helsinki (2 ESR), Finland**
- **UniGe (1 ESR), Switzerland**
- **CERN (2 ESR), Switzerland**
    - **LHCb**
    - **ATLAS**
- **LPNHE/CNRS (3 ESR), France**
- **NIKHEF (2 ESR), Netherlands**
    - **LHCb**
    - **ATLAS**
- **Dortmund (2 ESR), Germany**
- **Lund (2 ESR), Sweden**
    - **ALICE**
    - **ATLAS**
- **Heidelberg (1 ESR), Germany**

Academic partners:

- **Ohio State University, US**
- **University of Oregon, US**
- **University of Santiago, Spain**
- **University of Pisa, Italy**
- **University of Cincinnati, US**

Non-academic partners:

- Ximantis
- **KKT/Fleetmatics (https://www.fleetmatics.com), Italy**
- **CATHI, http://www.cathi-online.com , Germany**
- **Reflexive Investments http://www.reflexiveinvestments.com Switzerland [TBC]**
- **Wild Tree Tech, http://www.wildtreetech.com , Switzerland**
- **Heidelberg Instruments, https://himt.de/, Germany**

Non-academic beneficiaries:

- **Dreamquark, https://www.dreamquark.com, France**
- TBC

# List of SMARTHEP Early-Stage Researchers (work in progress)

**Note: industrial and academic secondments are only a preliminary matchmaking proposal, and they need to be discussed upon between ESR**

**institute supervisor and institute/industry where the student will be seconded. It is important to note that institute/industry can only host a limited number of students so this will in any case need re-evaluation after balancing.**

## HELSINKI

**Expertise and interests of the host institute:** Jet physics (inclusive jets, jet energy corrections, dijet resonances, trigger), charged Higgs searches (with taus)+ Higgs combination
**Expertise required for PhD project/secondment project:** Some experience with Tensorflow/DNNs or trigger/JEC would be a plus.
**Training/skills acquired during the PhD/secondment:** ESR1/2 --> real-time data analysis; software development and cooperation (Python, Tensorflow, github), statistical analysis for corrections and correlation

- Physics topics
    - Dijet searches, higgs boson as a tool for discovery
- ESR1
    - Experiment: CMS
    - Supervision: Mikko Voutilainen, Henning Kirschenmann
    - Topics: Data scouting in CMS, improve and validate HLT jet reconstruction
        - Academic secondment: Lund, ATLAS/CMS jet energy scale calibration and validation
        - Industrial secondment: Ximantis (Lund)
    - Draft text:

**Topics: Data scouting in CMS, improve and validate HLT jet reconstruction, perform "resolved" dijet mass search**
Academic secondment: Lund, ATLAS/CMS jet energy scale calibration and validation
Industrial secondment: TBC

Objectives:
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- Implement quick and continuous (eta) calibration of HLT jets using dedicated trigger streams (using high rate scouting stream)
- Do online/offline jet matching to transfer offline final corrections back to trigger level; explore usage of DNN to "transform" HLT jets to offline jets (improve resolution)
- Devise a joint strategy with ATLAS on how to correlate systematic uncertainties and align procedures to calibrate jets at HLT
- Perform dijet mass analysis in scouting and "standard" regime. Extend by considering dijet + hard radiation topology to reduce backgrounds.

Expected Results:
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- Improved performance of HLT-jets
- Contribute to trigger performance publication, presenting new techniques
- "Standard" dijet mass bump hunt, contribute to dark matter interpretation.

Planned secondment(s):
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- Lund for ATLAS/CMS cooperation on jet energy corrections at trigger level; Caterina Doglioni

- Industry: CATHI, TBC (real-time analysis focus)

- ESR2
    - Experiment: CMS
    - Supervision: Mikko Voutilainen, Henning Kirschenmann
    - Topics: Data scouting and machine learning in CMS (e.g. heavy flavor identification)
    - Academic secondment: CERN, Maurizio Pierini
    - Industrial secondment: Fleetmatics, Italy
    - Draft text:

**Topics: Data scouting in CMS, improve object tagging at HLT (flavor + heavy object) using machine learning, measure boosted Z->bb and H->bb**
Academic secondment: CERN, Scouting setup maintenance and improvements; work on deep learning techniques

Objectives:
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- Bring advanced object tagging techniques utilizing DNN to HLT in order to perform flavor+heavy object tagging with best possible performance during data-taking, already.
- Maintain a high rate “Particle Flow” scouting stream with low HT and jet pt-thresholds.
- Perform boosted Z->bb and boosted H->bb measurements (cf. HIG-17-010) as scouting analysis with lower thresholds and utilizing improved substructure and tagging HLT-techniques
- Perform extended “di-object” mass search for dark matter mediators utilizing flavor+heavy object tagging
- (Work on implementing a “deep scouting” that automatically monitors a wide set of topologies at high rate at HLT for anomalies.)

Expected Results:
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- Improved flavor/heavy object tagging at HLT that benefits also other analyses/trigger suites.
- Validate new flavor/heavy object tagging techniques at HLT by measuring Z->bb cross section.
- Establish boosted H->bb production to resolve the long- and short-distance contributions to the gluon fusion process.

Planned secondment(s):
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- CERN: Close collaboration with “scouting” and “deep learning” experts; Maurizio Pierini
- Industry: Fleetmatic, Tensorflow on mobile platforms

## UniGe

- Physics topics
    - Dark sectors and long-lived particles, SUSY
- ESR3
    - Experiment: ATLAS
    - Supervision: Anna Sfyrla
    - Topics: pattern finding algorithms for tracking in real-time (using Machine Learning) / implementation in CPU-GPU/ FPGAs (IBM)
    - Academic secondment: none

    - Industrial secondment: ReflexiveInvestment
- Draft text **Included in application**

**Machine learning for pattern recognition in searches for exotic physics at the LHC ATLAS experiment**

Objectives
=====

One of the biggest challenges in hadron collider physics is the presence of multiple proton interactions that occurs every time the proton bunches collide against each other. This is creating in the particle detectors extremely busy images that need to be deciphered fast and efficiently. Reconstructing tracks under these conditions is a major task and becomes even more challenging in the real-time needs of the trigger system. This challenge will only increase in the future, with the planned LHC upgrade.

The first objective of this project is the development of machine-learning-based tracking reconstruction as a replacement to existing tracking algorithms that are too slow to be used in real time. The ESR will be formed an expert on track reconstruction in the busy hadron collider environment, as well as modern machine learning techniques and tools for pattern recognition.

The tracking reconstruction in the full particle detector is a task that can be parallelised. This leads to the question whether GPUs are more appropriate processing units than CPUs are. The second objective of this project is the evaluation of GPUs for track reconstruction, especially at higher pile-up conditions of the LHC upgrades, an activity that will expand the knowledge and experience of the ESR to modern technologies. Currently, hardware tracking is planned as an alternative to software tracking for triggering purposes. The option of using GPUs with fast machine-leaning-based tracking has never been evaluated, and the ESR of this project will have the right expertise to answer this question.

The third objective of the project will be the application of the previous developments to a trigger for displaced vertices in the ATLAS tracking system, which have never been developed before. This is one of the most promising signatures for new physics and yet one of the most experimentally challenging. The ESR will use the data collected with that trigger to perform a unique search for exotic long-lived signatures at the ATLAS detector.

The work will represent a significant step beyond the existing reconstruction and triggering capability currently available at the ATLAS experiment. It will answer crucial questions for the future of the experiment and will open new roads in the searches for new physics. The work will be conducted within the experience ATLAS Univ. of Geneva team and will be will integrated in the ATLAS experiment.

Expected results:
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The ESR will lead two publications; a technical one of the machine-learning-based track reconstruction and evaluation on GPUs, and a physics one, on the search for new physics.

Planned secondments:
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Non-academic: ReflexiveInvestments (Switzerland) [9 months]

## CERN

- Physics topics
    - ATLAS: Dark sectors and long-lived particles, SUSY (upgrade).

    - LHCb: TBC
- ESR4
    - Experiment: ATLAS
    - Supervision: Brian Petersen
    - Topics: online tracking with machine learning, implementation in CPU/GPU / multithreading…
    - Academic secondment: LPNHE ATLAS or Heidelberg
    - Industrial secondment: IBM OpenLab or ReflexiveInvestments

Draft text **included**

Project Title and Work Package(s) to which it is related:
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Efficient Realtime Analysis using Multi-threaded Processing

Objectives:
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Over the last decade, the largest boost in computational power in commercial general purpose processors (CPUs) has come from increasing the number of computational cores in a single processor rather than the raw speed. To fully utilize the available processing power in a modern CPU, one increasingly have to rely on multi-threaded programming to divide the calculations over multiple cores running in parallel. Until recently in HEP the multiple cores could be utilized fairly efficiently by simply processing a different event on each core (multi-processing), but as the core count has increased this is no longer efficient and instead a more advanced, multi-threaded approach has to be employed. This is particularly challenging for real-time analysis, for instance in HEP trigger systems, where the overhead of doing multi-threaded processing might be large compared to the processing latency.

The first objective of this ESR is to ensure an highly efficient, multi-threaded implementation of the ATLAS high-level trigger system by implementing new monitoring capabilities to measure the algorithm scheduling and algorithm performance as well as the overhead of the multi-threaded system.
This should be used to analyze the resource usage and identify improvements that maximize the utilization of concurrent processing.

The second objective is to use the gained insights and knowledge to implement new realtime analysis capabilities in the ATLAS trigger system for long-lived particle signatures. For example, long-lived charged particles can decay in middle of the tracking volume, leaving just a short, straight trajectory of highly ionizing hits in the innermost layers. These could be identified already in the trigger system with a fast, dedicated pattern recognition algorithm.
This would increase the trigger acceptance for such particles in ATLAS Run-3 data and the ESR would be expected to take a lead on such an early data analysis.

Objective related to secondment to be added here.

The work will be conducted in the CERN ATLAS team and integrated in the
ATLAS trigger software group developing the ATLAS multithreaded execution framework.

Expected Results:
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This ESR will lead to two peer-reviewed papers. One will document the multi-threaded implementation of the ATLAS High-level Trigger system, while
the second one will be the results of the search for long-lived particles in the first ATLAS Run-3 data. The student connected to this ESR will receive a PhD in HEP at University of Geneva.

Planned secondment(s):
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To be decided, but **it would be most fitting to have an industry partner that needs realtime analysis with large enough computational load that a single core processor solution is insufficient. CD: This matches well what LPNHE is doing, creating pattern banks for FTK through matrix inversion.**

- ESR5
    - Experiment: LHCb
    - Supervision: Frederic Teubert
    - Topic: LFV
    - Academic secondment: Dortmund
    - Industrial secondment: IBM OpenLab or IBM France
- Draft text

Physics topic: Search for LFV in tau, strange and charmed mesons decays.
Topic: Preserve LHCb trigger performance at low PT in the Phase-1 upgrade.

Objectives:

LHCb will have a Phase-I upgrade in 2020 where the experiment will be fully read out at 40 MHz, allowing for a very flexible
full software trigger. This upgrade will be accumulating the same amount of data accumulated by LHCb between 2010 and 2020 in a single year, and multiply by more than a factor six the total accumulated statistics by 2029. However, the trigger algorithms will need to be revisited to deal with a higher rate and pileup. In particular, to maintain the LHCb trigger performance at low PT one needs to rethink completely the reconstruction algorithms. The ESR will be working on ways to speed up the reconstruction used at the trigger level, with emphasis on the unique low PT acceptance that LHCb has w.r.t. other LHC experiments. This key property of LHCb will allow to search for Lepton Flavour Violation processes in low-mass objects like taus, Kaons or Charm mesons, which will benefit from the much larger statistics available after the Phase-I upgrade.

## Dortmund

- Physics topics
    - Lepton Flavour Violation / universality in unflavoured mesons
- ESR6
    - Experiment: LHCb
    - Supervision: Johannes Albrecht
    - Topic: Develop framework for long-term monitoring and adjustment of total detector performance, so detector can self-calibrate (review ??)
    - Academic secondment: NIKHEF or Lund, inter-experiment monitoring infrastructure or NIKHEF/Olya on LFV inter-experimental
    - Industrial secondment: Ximantis (Lund)
- Draft text **included**

**Real time analysis MVA for Lepton Flavour Violation (WP: ML, WP: trigger)**

Objectives:

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The objective of this ESR is to advance the level of studies of Lepton Flavour Violation (LFV) to the next level. Currently, several experiments are proposed and constructed to investigate LFV.  So far, no process violating Lepton Flavour is observed. This ESR will search for LFV in neutral meson decays in the dataset of LHCb.

Current tests by older experiments reach a precision of about one in a million for decays of f, J/y and Y mesons, for example. At the upgraded LHCb detector, which will start data taking in 2020, many orders of magnitude more of these mesons are produced, allowing in principle to push the precision by orders of magnitude. Challenges are the difficult separation between these decays and the overwhelming background levels.

The first stage of the ESR will be a development of a real time selection for f, J/y and Y mesons decaying into the different lepton species. Because of the difficult experimental signatures, fast multivariate selections need to be developed. A possible extension of this work is the development of inclusive selections for these modes.

The second stage of the ESR will be the analysis and publication of the data prepared in the first stage. The dataset has the potential to boost the precision of these tests for LFV by several orders of magnitude.

This work will be conducted within, but will represent a significant extension to the ERS Starting grant that J. Albrecht holds at TU Dortmund.

Secondments: machine learning, real time, analysis

Industry: Ximantis
Academia: NIKHEF (LHCb or ATLAS)

- ESR7
    - Experiment: LHCb
    - Supervision: Johannes Albrecht
    - Topic:  Investigate if trigger decision can be done on event properties without reconstructing objects, using MVAs
    - Academic secondment: CERN LHCb
    - Industrial secondment: Wild Tree (Switzerland)
- Draft text **included**

**Event Triggering (WP: ML, WP: trigger)**

Objectives:

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Trigger systems of modern HEP experiments reduce the event data processed in real time by several orders of magnitude. The paradigm so far has been to reconstruct objects as first step (e.g. jets or tracks) and then perform a selection on these objects.

The objective of this ESR is to develop trigger based on global event properties, where decisions if the event contains interesting physics is taken without the time intense reconstruction of objects. Initial studies in the frame of the ERS Starting grant of J. Albrecht have shown that this approach has a great potential to identify interesting primary vertices, however, much more detailed studies need to be performed. If successful, event triggers can allow new classes of physics selections and therefore open new windows for searches for physics beyond the SM.

The first step of this ESR will be the analysis of the direct pattern of detector measurements to identify interesting vertices and generally events with an enhanced  content of interesting physical processes. This analysis will be used to deliver the event trigger selection and benchmark its performance against a more traditional approach.

The second step of this ESR will be the analysis of semileptonically decaying beauty decays, that can be used to test Lepton Flavour Universality (LFU). These decays are frequent enough to benchmark the traditional trigger selection against the event trigger.

Secondments: ML, trigger, global analysis of data.

Academia: Lund
Industry: Wild tree

# LPNHE

- Physics topics
    - ATLAS: Hadronic resonances as dark matter mediators
    - LHCb: Lepton Flavour Violation
- ESR8
    - Experiment: ATLAS
    - Supervision: Francesco Crescioli, Bogdan Malaescu
    - Topic: Fast TracKer for real-time analyses
    - Academic secondment: Pisa
    - Industrial secondment: Fleetmatic, Apache Spark
- Draft text **included**

Project Title and Work Package(s) to which it is related:
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Real-time particles trajectory reconstruction for on line event selection and analysis

Objectives:
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This project aims at training researchers in the usage of advanced computing techniques for real-time analysis in fields of Physics or XXX, as well as to contribute to searches for physics beyond the Standard Model ("new physics") with the ATLAS detector. The main goal is to study and improve the real time reconstruction of the trajectories of charged particles in the ATLAS experiment using the hardware tracking processor FTK and FTK++.

(part to be used in main text)
The ATLAS trigger infrastructure has an unique hardware processor to reconstruct the trajectory (tracking) of the charged particles that cross the silicon inner tracker of the experiment. The tracking information is an essential tool for effective real-time event selection and has a central role in the whole ATLAS physics program especially in the HL-LHC phase. The current hardware processor, FTK, is a complex system made by several custom electronics  boards based on FPGAs and Associative Memory chips. The latter are unique computing devices developed for the FTK algorithm. The hardware tracking will be also a central part of the Phase-II Upgrade of ATLAS, with upgraded version of FTK called FTK++.
(end of part to be used in main text)

The tracking performances such as efficiency and resolution of the parameters are not determined just by the hardware capabilities, but mostly by a database (pattern bank and geometrical constants) loaded into FTK/FTK++ and produced by a training procedure. By improving and tuning the training procedure it is possible to continuously improve the tracking performances and optimize its use for new physics searches.

The first objective of the ESR will be to develop advanced statistical and computing techniques, such as Principal Component Analysis and Graph Clustering toolkits, in order to produce new databases for FTK and evaluate their impact on raw performances and physics analyses. The developed toolkits will also allow to extend the application of FTK-like algorithms to applications outside the High Energy Physics field, such as real-time image recognition or genomic data analysis, by providing flexible and powerful tools to train datasets.

The second objective of the ESR will be to investigate in detail the impact of new training on selected physics cases. In particular FTK tracks will be used to improve the jet reconstruction and calibration, namely for the suppression of pile-up jets and the track-based components of the global sequential calibration. This will enhance the sensitivity of the new physics searches using a real-time trigger level analysis of dijet mass distributions.

Expected Results:
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This ESR project will lead to two peer-reviewed papers, one documenting the toolkits developed and the improvements on the tracking performances, and one documenting the real-time trigger level analysis of dijet mass distributions using FTK tracks. The toolkits developed for the training of datasets will be adapted for usage outside of the ATLAS experiment and released. The student connected to this ESR will receive a PhD at UPMC in Paris.

Planned secondment(s):
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A XXX secondment in YYY will allow for training in for physics training and interaction with the ATLAS collaborators involved in the real-time trigger level analysis efforts, as well as training in the integration of FTK tracks in the analysis framework, under the supervision of XXX.

⇒ Comment from Anna: This student could be also hosted at UniGe if you wish, I think there is common interest in the project and FTK expertise in the group so the student could work with people here.

- ESR9
    - Experiment: LHCb
    - Supervision: Vladimir Gligorov
    - Topic: TBD
    - Academic secondment: CERN or Dortmund
    - Industrial secondment: ReflectiveInvestments, if CERN?
- Draft text: **included**

Project Title and Work Package(s) to which it is related:
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Real-time financial analysis and new physics searches

Objectives:
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The goal of this project is to train ESRXX in methods for real-time data analysis, including the identification and elimination of adversarial examples in classifier training, the development of recurrent neural networks and identification of the most important patterns which these networks rely on for their classification,
and the use of heterogenous time-ordered and non-time-ordered datasets in real-time analysis. In all of this work, the ESR will benefit from being trained at DreamQuark, who are industry leaders in these topics, particularly when applied to financial or medical insurance applications.

ESRXX will work on developing DreamQuark's real-time analysis software in two main ways. First of all, they will work on a dedicated software framework for identifying, classifying, and eliminating adversarial examples, which look similar to the human eye but differ at the pixel level. For instance, a self-driving car could be misled
by pixel-level changes to a road-sign which a human would not even notice. ESRXX's framework will automate the process of generating adversarial examples by systematically varying training datasets for classifiers, and

then teach the resulting network to ignore such changes in its training. ESRXX will also work on DreamQuark's deep-learning
infrastructure, and in particular in understanding which patterns of information DreamQuark's recurrent neural networks use to take their decisions. This will then allow
ESRXX to improve this framework to allow the use of non-time-ordered data sources together with time-ordered data in order to take better decisions, particularly about financial
investments or medical insurance.

Finally, the adversarial example framework's generality will allow it to be used in a search for New Physics in the decays of strange hadrons with the LHCb
experiment. In particular, the method will be applied to search for lepton-flavour decays of strange hadrons, which are particularly interesting in light
of hints of lepton non-universality seen by LHCb and other experiments. The major backgrounds in such searches are in fact adversarial examples, generated by
much more frequent Standard Model decays of strange hadrons with identical topologies but different final state particles. The use of the framework developed
by ESRXX will allow these analyses to be performed in real-time, and increase their sensitivity by two orders of magnitude.

Expected Results:
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This ESR project will lead to two concrete commercial deliverables : a framework for identifying and eliminating adversarial examples in real-time
algorithms, and a framework for combining non-time-ordered data sources together with time series in real-time analysis. Each of these commercial deliverables
will be released as a software package. It will also lead to
an academic deliverable : a peer-reviewed paper which will use the adversarial example framework to search for New Physics in rare decays of strange
hadrons with the LHCb detector. The student connected to this ESR will receive a PhD at UPMC in Paris.

Planned secondment(s):
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A four-month secondment at CERN will allow for physics training and interaction with the LHCb collaborators involved in the physics analysis,
as well as training in the development of new software tools under the supervision of Rosen Matev. A five month secondment at Santiago de Compostela
will allow ESRXX to adapt and deploy the adversarial example framework to the search for New Physics, under the supervision
of Veronika Chobanova.

- ESR10
    - Experiment: Interexperiment/computing lab at Paris6: LIP6
    - Supervision: UPMC/LIP6 (Lionel Lacassagne)
    - Topic: hybrid infrastructures for real-time analyses, framework to implement real-time analyses in hetereogeneous architectures (GPU talk to CPU)
    - Academic secondment: CERN
    - Industrial secondment: IBM for GPU
- Draft text: **included**

Project Title and Work Package(s) to which it is related:

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**Enabling real-time analysis on heterogeneous computing architectures**

Objectives:
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The goal of this project is to, in partnership with NVIDIA, train ESRXX in programming for heterogeneous computing architectures, and in particular simultaneously optimizing data formats and processing techniques to enable CPUs, GPUs, FPGAs, and hybrids to work together to solve problems which none of these technologies could solve on their own. The ESR will subsequently use this training to design a novel machine learning method for optimizing heterogeneous computing architectures, and deploy it in the context of the specific requirements of real-time data processing in the LHCb and ATLAS collaborations.

With the end of Moore's law and the increasing parallelization and diversification of computing architectures, it becomes increasingly complicated to design an optimal architecture for a processing task. Particularly for complex tasks, such as the real-time data processing of LHC experiments, there may be many constraints involved : the I/O limitations of each architecture, the memory limitations and compilers used, the optimal scheduling of subprocesses within each task. Such a multidimensional optimization problem is perfect for the deployment of modern machine learning techniques. The first objective will therefore be to develop a machine learning based optimization of such a system, which takes as input the cost of the various computing architectures under consideration, builds and emulates test processing systems, tests them using the task being optimized for and finds the most cost-effective one. The second objective will be to apply this optimization code to the specific problems of the LHCb and ATLAS real-time data-processing architectures.

Expected Results:
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This ESR project will lead to two peer-reviewed papers, one documenting the novel machine learning based optimization of heterogeneous computing architectures, and one documenting the application of this method to the optimization of the LHCb and ATLAS real-time data processing. *Can we find a viable commercial use for this with IBM, which could be added as a deliverable?*

Planned secondment(s):
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A five-month secondment at CERN will allow for training in machine learning methods and interaction with the LHCb and ATLAS collaborators involved in the optimization of their respective real-time analysis systems, under the supervision of Brian Petersen and Ben Couturier. A four month secondment at NVIDIA will provide ESRXXX with valuable training on the optimization of heterogeneous architectures, under the supervisionof (insert commercial link here).

## NIKHEF

- Physics topics
    - ATLAS: LFV
    - LHCb: LFV
- ESR11
    - Experiment: ATLAS
    - Supervisor: Olya Igonkina
    - Topic: development of inter-experiment tools that will be used for optimization of trigger resources / grid computing
    - Academic secondment: CERN for ML with tracking / muons

    - Industrial secondment: CATHI (Heidelberg)
- Draft text **included**

Project Title and Work Package(s) to which it is related:
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Smart optimization of resources for efficient trigger and analysis

Objectives:
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Also this project aims at bringing advanced machine learning tools into trigger and analysis. However, instead of focusing on specific physics processes and separation of signal versus background based on the characteristics of these processes, we will investigate a more generic approach - what are the bottlenecks in our trigger algorithms, what prevents us to record events we want and how to do more exciting physics with same or even less resources we have. The typical bottlenecks for real-time processing are : available CPU, available memory and available disk space. The main limitations come from necessity to accomplish the work in very specific and short time as well as necessity to reduce the incoming data by factor within few milliseconds.

So the problem : ATLAS is general purpose experiment with huge variety of interesting physics processes. The number of scientific papers is about few hundred per year. The trigger that serves this rich physics program consists of few thousands trigger lines, developed by a hundred of physicists with different programming skills. Although, a highly trained and experienced team puts everything together and optimize the submitted code to a high degree, this manual work requires a lot of attention and tests and is error prone. Further, constantly improving LHC performance (high luminosity of events, higher density of interactions, higher volume of data) makes the optimization of trigger software and hardware a continuous battle to satisfy constant limits and sustain design output parameters.

We aim to simplify, streamline and optimize this processes, but creating the tools that will analyse each trigger line performance, resources used and as well as common parts of different lines and minimize the resources consumptions using machine learning approach. As the tools will not use physics characteristics in optimization (except for "physics independent approach", when such characteristics are used to group triggers together or to select the most optimal step without loose of physics performance), they will be portable and useful for applications outside of ATLAS experiment. As an example we will design the tools together with LHCb trigger colleagues (ESR12). LHCb experiment has similarly complex trigger system and similarly complex set of limitations/bottlenecks, where such tools could be applied.

To bring personal connection and to prove of the concept, the work of ESR student will continue in Lepton Flavor Violation search tau to 3 muon leptons with ATLAS data, where again optimization of the analysis chain (with less focus on resources and more focus on characteristics of background processes) is critical. At this point is not clear how to preserve this very challenging physics process at the ATLAS trigger system. The application of the tools that we will design in this project is a critical ingredient for enabling such a discovery.

Lastly, we believe such tools are software independent and are useful outside ATLAS environment, be this LHCb experiment or industrial group that manages large software projects. To make these tools fully problem independent, we will collaborate with CATHI firm first testing these tools in their environment and further making the tools available to them for the benefits of their customers, that will get faster and smarter software with gain in the performance.

Expected Results:
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- Improved ATLAS trigger performance, allowing more physics channels and therefore more scientific output
- industry quality tool to speed up software and limit its CPU and memory consumption .
- Preservation of lepton flavor analysis tau to 3 muons at high luminosity LHC
- development of SMART tools to improve physics performance by optimizing resources and reusing common parts
- application of SMART tools to an alternative software project such as LHCb experiment and CATHY firm software
- paper on machine learning optimization based on resources and not on output parameters
- paper on trigger for Lepton Flavor Violation of tau to 3 muons with ATLAS
- The student connected to this ESR will receive a PhD at Radboud University in Nijmegen, NL.

Planned secondment(s):
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%%%%%% Frank Winklmeier would match very well to the topic for secondment. %%%%%%% Johannes Albrecht could be good for LFV link (well almost) %%%%%%% LHCb trigger for common tools, but here we have Gerhard. %%%% We might have FTK expert in Nijmegen soon, then we can also strengthen link to Vava, if needed.

A XXX secondment in YYY will allow for training in machine learning interaction with the ATLAS collaborators. The secondment at XX is crucial to get the student up to speed with modern ATLAS trigger tools. The secondment at CATHY, Heidelberg is critical for the test of the designed tools in a different environment and dissemination.

- ESR12
    - Experiment: LHCb
    - Supervisor: Gerhard Raven
    - Topic: development of inter-experiment tools that will be used for optimization of trigger resources / grid computing
    - Academic secondment: LPNHE for computing aspect
    - Industrial secondment: TBC
    - Text: see above and split

## Lund

- Physics topics
    - ATLAS: search for Dark Matter mediators
    - ALICE: TBD
- ESR13
    - Experiment: ALICE
    - Supervisor: Peter Christiansen
    - Topic: O2 ALICE real-time analysis upgrade
    - Academic secondment: CERN
    - Industrial secondment: ReflectiveInvestments (Geneva)
- Draft text:

**On the fly calibrations and analysis of the ALICE Time Projection Chamber**

**Supervisor:**
Peter Christiansen (PC), Lund University.

**Background:**
In 2019-2020 LHC will be shut down to upgrade and prepare the experiments for Run 3. The goal of the ALICE upgrade is to be able to analyse the full rate of events, 50kHz, online thereby increasing the sensitivity for most measurements by between an order and two orders of magnitude.
PC is involved in both detector upgrades and data analysis. The main goal on the detector side is the upgrade of the TPC with a Gas Electron Multiplier (GEM) readout that will allow continuous operation. The continuous readout requires a whole new software framework denoted $O^2$ (online-offline). The goal of the framework is to do full calibration and reconstruction in real time (RTA).
The Lund heavy-ion group is since long time active in the ALICE TPC project. Sweden has contributed with around 21MSEK (~2M€) to the TPC detector. PC is one of two coordinators of ALICE TPC GEM upgrade simulation activities responsible for the implementation of the GEM TPC simulations in the $O^2$ framework.

**Project:**
The goal of the project is to contribute to the development of $O^2$ framework and use this expertise in the analysis of the first data from Run 3, which will start in 2021.
The upgraded TPC will have to be calibrated for large distortions due to charge build up. These distortions are of order cm and have to be calibrated with sub mm precision over a space volume of 90 cubic meter. Due to charge fluctuations the calibration maps will have to be updated every 5 milliseconds or so. This demands fast, effective and robust algorithms that the student will have to develop and benchmark.
The main goal of the ALICE project is the analysis of heavy-ion data, which will first be available after roughly one year of proton-proton (pp) data. This means that the Ph.D. student will have time to develop the framework during the shutdown (2019-2020) and then validate it with pp data before he or she will apply it to one of the first analyses with the upgraded data. This analysis will likely be a measurement of the nuclear modification factor since this will be very sensitive to the corrections.

**Expected Results:**
This ESR will lead to two peer-reviewed papers. One will be on the calibration and reconstruction performance of the upgraded TPC and one will be on one of the first results in Run 3. The student connected to this ESR will receive a PhD in HEP at ULUND.

**Planned secondment(s):**

A six-month secondment at CERN will allow for training and interaction with the core of the ALICE O2 development team (which is located at CERN).

- ESR14 (looking for industrial beneficiary, maybe IBM?)
    - Experiment: ATLAS
    - Supervisors: Caterina Doglioni, Oxana Smirnova
    - Topic: real-time calibration in ATLAS and interexperiment monitoring tools
    - Academic secondments: CERN (physics analysis, working with OSU and Oregon on TLA and topoclustering)
    - Industrial secondment: Fleetmatic
- Draft text: TBC once the industrial beneficiary is there

## Heidelberg

- Physics topics:
    - ATLAS: long-lived particles, multijet TLA
- ESR15
    - ATLAS: Monica Dunford, Pavel Starovoitov
    - Topic: Precise trigger object calibration for phase-2 upgrade, pile-up mitigation techniques, use of FTK
    - Academic secondment: Pisa for FTK hardware
    - Industrial secondment: Heidelberg Instruments (Heidelberg)
- Draft text

Project Title and Work Package(s) to which it is related:
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Reduction of the low- and high-energy physics noise in searches for new physics phenomena beyond the Standard Model

Objectives:

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This project will prepare a researcher with expert-level understanding of the operation and calibration of the large-scale high-energy physics experiments trigger systems and deep knowledge of the statistical analysis of the experimental data in searches for the new physics manifestations. The ESR will learn the maintenance of the trigger systems in the commercial applications. The first objective of the ESR is the development and validation of the pileup noise reduction algorithms in the ATLAS Calorimeter trigger system. The second goal of the project is the suppression of the known Standard Model backgrounds in the events with at least four hadronic jets in the final-state in a search for Dark Matter particles using angular analysis together with mass-drop techniques.

Signals of new physics phenomena in the events with at least four jets can be distinguished from known Standard Model background processes using the information on the angular correlations between the final-state objects as well as the properties of the dijet masses in the four-jet system. The use of real-time (trigger-level) analysis will allow the identification of an interesting events and the early stage possible and use of further discriminants that will improve on the sensitivity to new phenomena. Statistical methods of data analysis, xFitter, will be used to quantify the result of this search and establish the level of agreement between the measurements and predictions.

The third objective of the project is the transfer of the experience in building and operating the 40 MHz trigger system in the ATLAS experiment to the commercial sector, Heidelberg Instruments company, where the typical trigger systems work at about 1 kHz rate. The increase of the rate will allow to shorten the production of most complicated samples from several days to hours.

Expected Results:
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This ESR will lead to two peer-reviewed papers: on the new system of the preprocessing of the calorimeter signals and on the search for new physics in the events with multiple hadronic jets in the final-state. The first one will contain a description of the real-time algorithms of the pileup corrections in the trigger system. And the second one with results of the application of the information on the angular correlations and dijet mass properties in real-time (trigger-level) analysis. The industrial part of this ESR will results in a development of the hardware+software system for a trigger system of the equipment produced by the Heidelberg Instruments. The student employed under this ESR will receive a PhD degree in HEP at the Heidelberg University.

Planned secondment(s):
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A four-month secondment at CERN will allow for physics training supervised by Antonio Boveia and Brian Petersen and interaction with the ATLAS collaborators involved in the operation of the Level-1 calorimeter trigger-system under the supervision of David Strom. A six-month secondment at Heidelberg Instruments under the supervision of Roland Kaplan will be used to develop the hardware and software tools for the commercial trigger systems and will train the ESR in application of academia skills in the industrial sector.

- **International/US partners at CERN (for secondment purposes only)**
  - **CERN/CMS**
    - Expertise: TBD
    - People: TBD
    - Supervising secondment of: Helsinki (ESR 2)
  - **CERN/ALICE**
    - Expertise: TBD
    - People: TBD
    - Supervising secondment of: Lund (ESR 13)

- **CERN/ATLAS/Oregon**
  - Expertise: trigger menu, topoclustering
  - PI: Stefanie Majewski, David Strom
  - People: Frank Winklmeier, Kate Whalen
  - Supervising secondment of: Heidelberg (ESR 15) and/or Lund (ESR 14) and/or LPNHE (ESR 8)
- **CERN/ATLAS/OSU**
  - Expertise: real-time analysis, FTK monitoring
  - PI: Antonio Boveia
  - People: Emma Tolley, Bryan Reynolds
  - Supervising secondment of: Lund (ESR 14) and/or Heidelberg (ESR 15)
- **CERN/LHCb**
  - Expertise: LHCb trigger
  - People: Sascha Stahl
  - Supervising secondment of: Dortmund (ESR 6, 7) or LPNHE (ESR 9)

Industrial partners:

1) a company doing traffic predictions and self-driving cars, Ximantis (http://ximantis.com), based in Lund (Sweden) - the student would also receive supervision from me

2) a company working on self-driving cars and GPS fleet tracking based in Florence, Fleetmatics (https://www.fleetmatics.com)

3) a company on medical technologies, CATHI, http://www.cathi-online.com

4) a financial investment company based in Geneva, http://www.reflexiveinvestments.com

5) Artificial Intelligence consulting and training in Zurich, Wild Tree Tech, http://www.wildtreetech.com
Expertise and interests of the company: consulting and development of software tools for data intensive science/industry. Deliver training courses on machine-learning and collaborative software development. Known good actor in the open-source community, lead developers for several open-source projects related to machine-learning and genomics. Experience mentoring students through Mozilla Foundation's Open Leadership Training.
Expertise required for secondment project: experience with python data ecosystem, asynchronous communication,
Training/skills acquired during the secondment: state of the art artificial inteligence solutions, modern software development practices, translating business needs into project priorities.

6) Heidelberg Instruments, https://himt.de/

7) Dreamquark, https://www.dreamquark.com