Real-Time Physics For LHCb Upgrade

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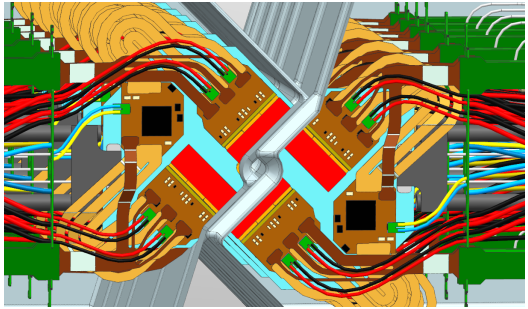
Introduction: VeLo Upgrade



VeloPix

- Moving from Si strip detector to pixel detector
- Sets of mounted chips surrounding beam line
- $(55\,\mu m)^2$ pixels give lower occupancy, improved track reconstruction
- Onboard ASICs can operate at luminosity of $2 \times 10^{33}\,cm^{-2}s^{-1}$

VeloPix Tile Testing

Pipeline

TSMC

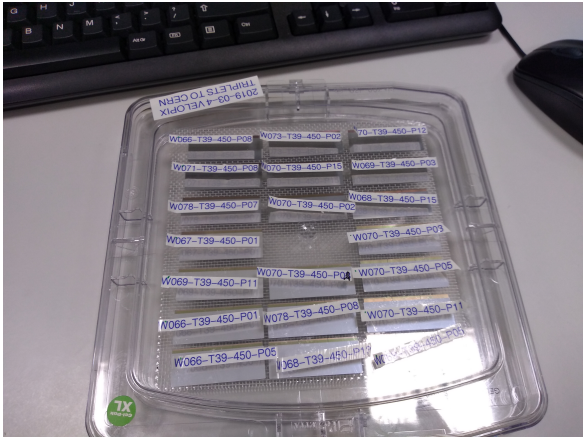
- Fabrication

→ Advacam

- Bump bonding
- Bow measurements
- IV scan (0 → 300V)

→ CERN

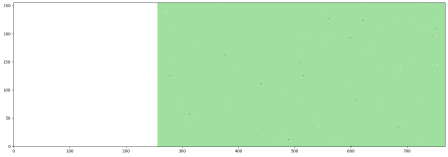
- Powerup and register tests
- Equalisation analysis
- Source scans (Sr90)
- IV scan (0 → 1000V)



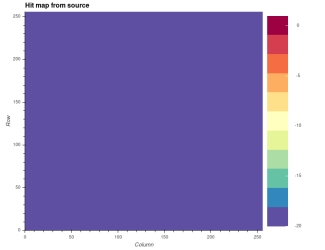
Analysed 66 triplet tiles

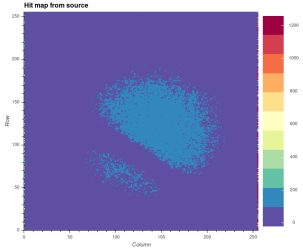
Tile QA – Failed Tile Example

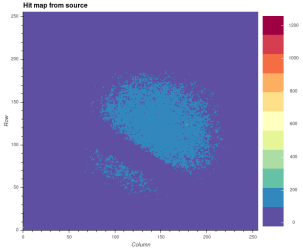
Powerup & Register Tests



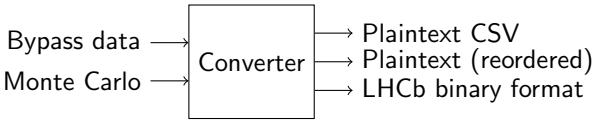
Source Scan

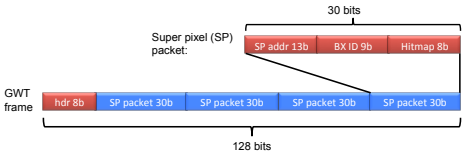






VeloPix Test Pulse Analysis – Decoder Software





Wrote VeloPix Bypass Decoding Software

- High-rate, many-to-many decoder for binary test pulse format data from gigabit transmitter, written in C
- Converts between multiple formats, and decodes output signal from VeLo
- Can also reorder hits, analyse outgoing data, detect encoding errors or dropped hits
- Includes helper tools that can be pipelined together
- lbtwiki.cern.ch/bin/view/VELO/VeloOct18Testbeam#C

Software Stack

Wrapper executable

↓

Master function

↓

Decoding/analysis hooks

↓

Basic bitstring library

VeloPix Test Pulse Analysis

- Send fixed, known hit pattern into Velo ASICs at regular clock cycle interval
- Receive binary data from output data bypass
- Decode positions and timings and compare input to output

Bandwidth Analysis

- Send simple input pattern to single ASIC
- Increase bandwidth to rated maximum and check for dropped pixels

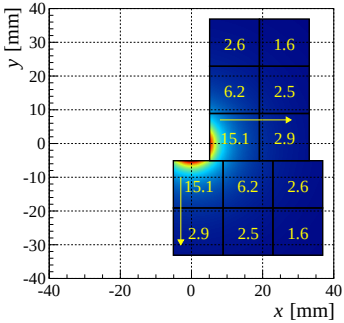
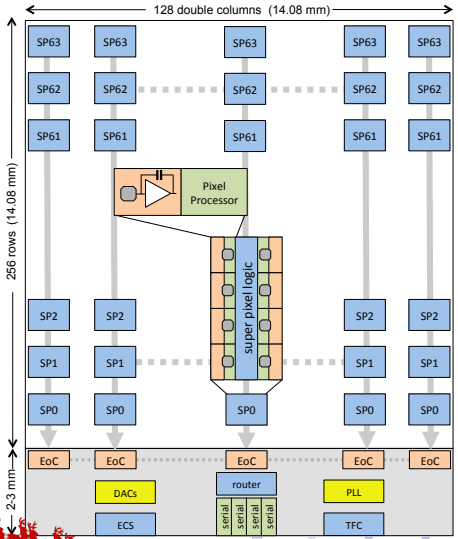


Figure: Per-ASIC data rate specification for hottest Velopix module (GB/s)

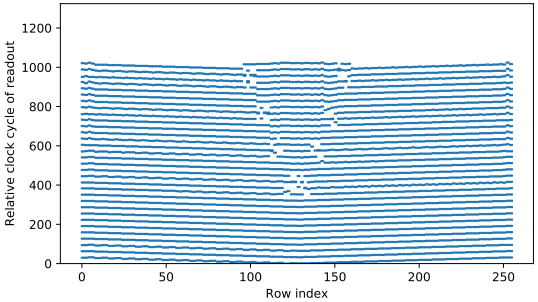
VeloPix Test Pulse Analysis – Results

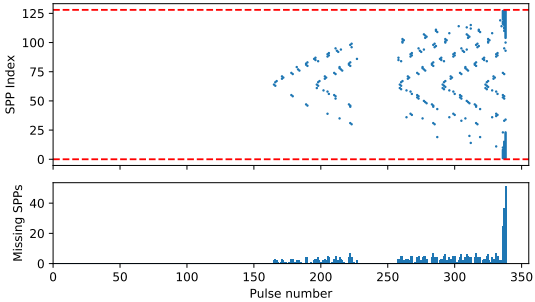
Bandwidth Analysis

- No dropped pixels until precise rated limit (160M super-pixels/s)
- At burst bandwidths that overflow buffers, pixels dropped from middle outwards



VeloPix Test Pulse Analysis – Results

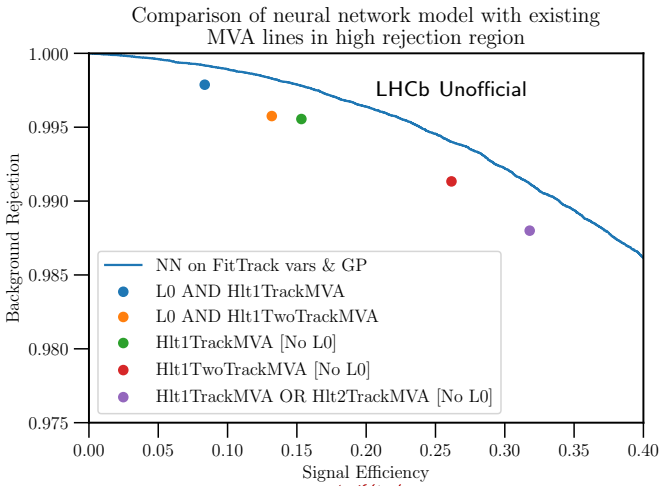




Trigger Line Retuning

Work on High-Level-Trigger

- NN trained on same variables as existing MVAs gives better results for some metrics
- Published an LHCb internal note on results (cds.cern.ch/record/2671546)
- Discussed with LHCb selections group on methods for tuning inclusive trigger MVAs for LHC Run 3
- Considerations made over GPUs



STFC Placement – Exgence Placement

Spent 6 months on non-physics industrial placement at tech startup Exgence Ltd.

Invitation-To-Tender Service

- Lead development of NLP service for software *invitation-to-tender* documents
- Automatically extract and sanitise information from abritrarily-structured documents
- Process through training and evaluation over multiple machine-learning models
- Link semantically similar entries to produce automatic suggestions to users on frontend

Summary

- Wrote LHCb internal note on trigger optimisation work
- Began work using Run 3 MC for trigger redesign
- Did test pulse analysis on Velo upgrade and wrote decoder software
- Worked 6 months at industrial placement

Backup Slides

Trigger Optimisation Required

Tracks to process increase more than computing resources

- Current inclusive trigger line applies fit to all tracks
- Fit takes $>$ **10**ms/event ($\geq$ **0.5**ms/track)
- Estimated **13**ms/event max mean processing time in upgrade
- Selections may need to be applied *before* track fit

Run 2 Inclusive-b MVA (Multi-Variate Analysis)

- Inclusive b-enriching decision on per track basis (passes based on outcome of tighter cut for single track OR looser cut for two tracks)
- Uses set of cuts on variables and output of a BDT
- Would different MVA model give any improvement?

Methods

- See how a simple neural network compares to existing MVA at identifying b tracks
- Extract event and track information from inclusive-b MC
- Tracks assigned ancestor number based on highest particle type ranking:

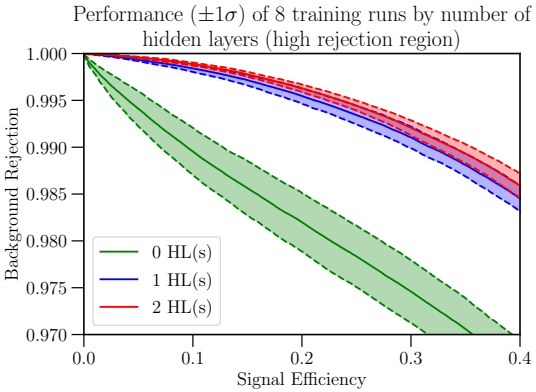
$$\text{Rank } R_{particle} : R_{long} > R_b > R_c > R_s > R_{u,d} > R_{ghost}$$

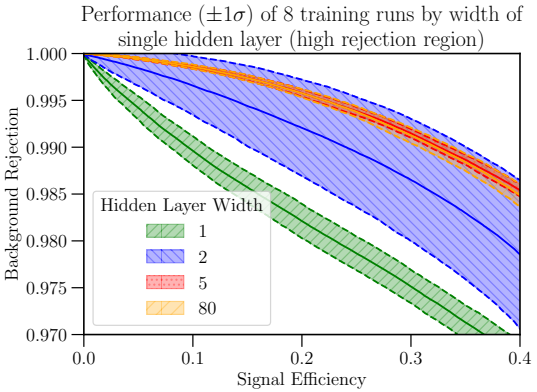
- Train on track variables with machine learning library (PyTorch)
- 2 output classes: Whether or not track has b label

Data Used

- 60 000 non-triggered MC-simulated events, generated for inclusive-b interactions,Run2, 2016 conditions
- 65% of events or 12% of tracks come from b quark
- MC201610000000Beam6500GeV-2016-MagUp-Nu16-25ns-Pythia8Sim09bXDIGI.py
  MC201610000000Beam6500GeV-2016-MagDown-Nu16-25ns-Pythia8Sim09bXDIGI.py

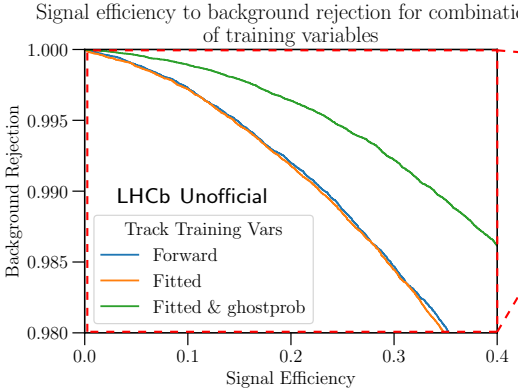
Hyperparameter Search

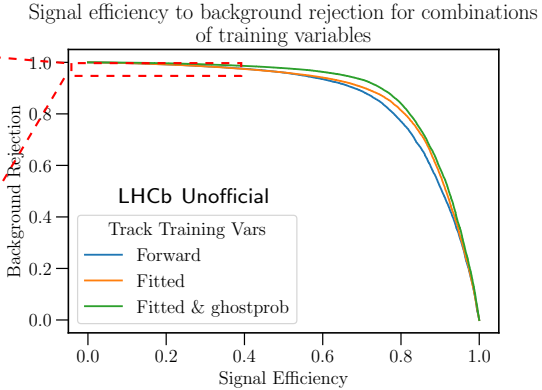




- Limit of performance at around **2** layers **10** — **20** neurons wide
- ReLU activation often means dead neurons — LeakyReLU fixes this
- Learning rate & batch size have little effect on classifier performance

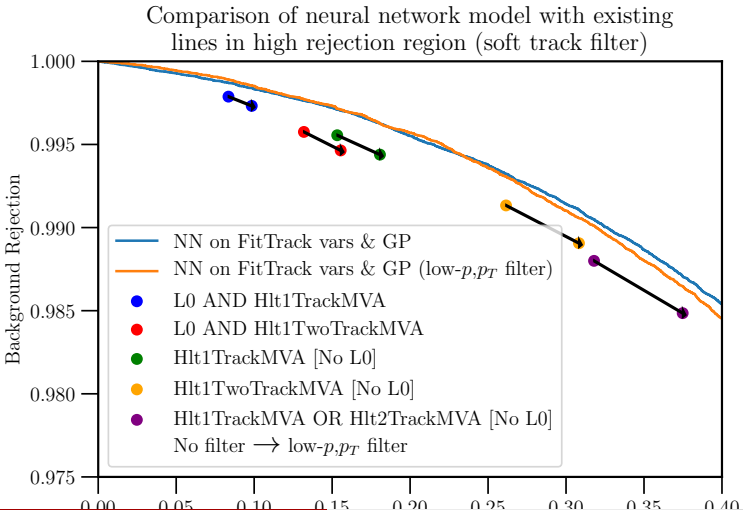
Track Classifier Variables





- Forward track vars $\xrightarrow{\textbf{Kalman filter – refinement \& outlier rejection}}$ fitted track vars
- GhostProbability valuable at high background-rejection regime

Classifier Performance Comparison



Neural net and MVAs with and without soft-track filter ($p_T > 570$ MeV, $p > 4750$ MeV)

Two-Stage Classifier

Current HLT1TrackMVA Setup

Create (forward) tracks from fast PR.

↓

Fit (almost) all tracks (expensive). Create fit track vars and ghostProbability.

↓

Perform selection with MVA on fit track vars.

Proposed Setup

Create (forward) tracks from fast PR.

↓

Perform first selection with forward track vars.

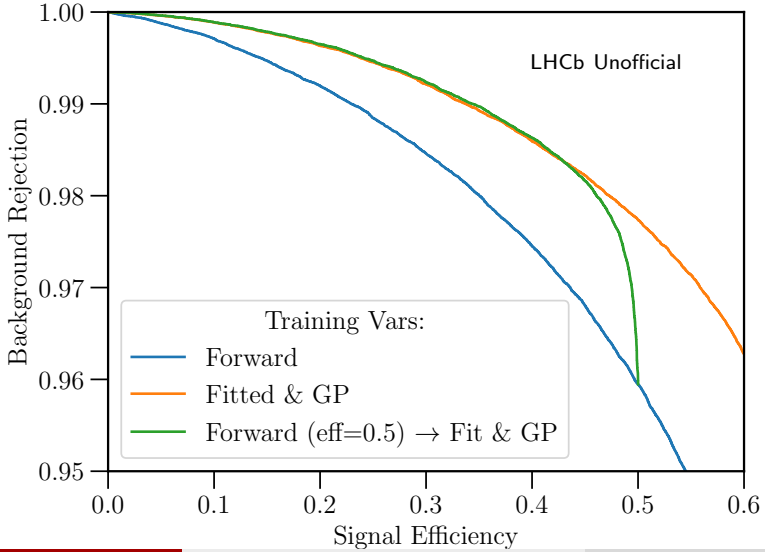
↓

Fit remaining tracks. Create fit track vars and ghostProbability.

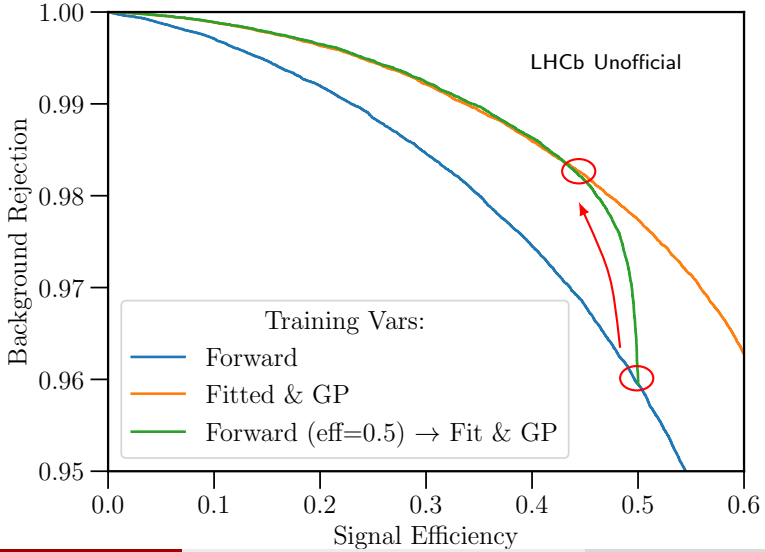
↓

Perform second selection with fit track vars + ghostProb.

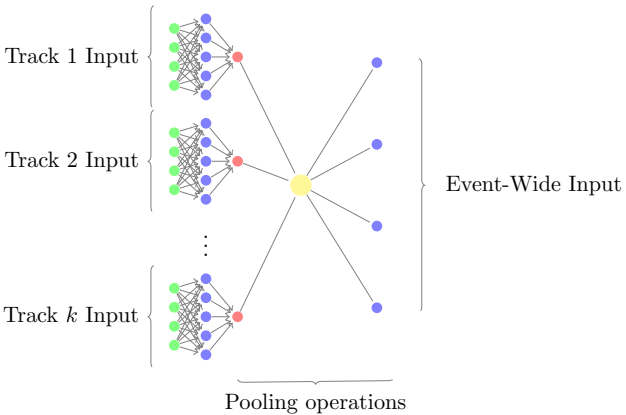
Two-Stage Classifier



Two-Stage Classifier



Classifying Whole Events



Pooling Outputs

- Classify each track separately with feed-forward NN
- Put outputs through pooling functions to 2nd NN
- Slightly better than cutting on highest output value

Current HLT1MVA Lines

HLT1TrackMVA

```
 SELECTION('%(input)s')
>> (TRCHI2DOF < %(TrChi2)s)
>> (TRGHOSTPROB < %(TrGP)s)
>> (((PT > %(MaxPT)s) &
(BPVIPCHI2() > %(MinIPChi2)s)) |
( in-range( %(MinPT)s, PT, %(MaxPT)s) &
(log(BPVIPCHI2()) > (%(Param1)s / ((PT / GeV - %(Param2)s) ** 2) + (%(Param3)s /
%(MaxPT)s) * (%(MaxPT)s - PT) + math.log(%(MinIPChi2)s)))))
```

MinPT	1000 MeV	TrGP	0.2	MVA, MVALoose:
MaxPT	25000 MeV	GEC	Loose	Param3: 1.0
MinIPChi2	7.4	Param1	1.0	MVATight:
TrChi2	2.5	Param2	1.0	Param3: 2.3