Run-3 offline data processing and analysis at LHCb

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LHCb is a forward arm spectrometer specialising in decays of beauty and charm hadrons.

LHCb in run 1 + 2

9 fb⁻¹ collected in run 1 + 2
>10^{12} bb pairs in acceptance
LHCb Upgrade I - Hardware and software Upgrade

- New pixel vertex detector (VELO)
- New silicon upstream tracker (UT)
- New scintillating fibre tracker (SciFi)
- New optics and photodetectors (RICH)
- New electronics (CALO, MUON)

Inst. Lumi. increasing by factor 5 up to $2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$

Target Int. Lumi. for Run 3 $50 \text{fb}^{-1}$

New fully software trigger - all sub-detectors must read out at 40MHz

HLT1 to run on GPUs

In Run 3 the data rate will increase by factor 30 compared to run 2...

See talk by Marianna
Data Processing and Analysis (DPA) in Run 3

- Increased data rate in Run 3 poses significant offline data processing and analysis challenges
- Coordination of these activities by DPA project
  - Software project on same level as detector projects

See talk by Peilian
DPA work packages

WP1: Sprucing
- Offline, central data skimming and slimming
- Sharing of HLT2 framework
- Ensemble of “Sprucing selections” from physics WGs run concurrently with data and during EoYS

WP2: Analysis Productions
- Centralised nTuple production using DIRAC production system
- Maximal automation
- Inbuilt testing/validation and analysis preservation

WP3: Offline analysis tools
- Offline analysis application sharing
- HLT2/Sprucing tools
- Modern/flexible design to be used with AnaProds
- Thread safe application

WP4: Innovative analysis
- R&D for innovative analysis techniques to be adopted in the future by LHCb
- Quantum computing

WP5: Legacy data & software
- Continued re-strippering (slim/skim) of legacy Run 1+2 data
- Maintenance of legacy software stacks for Run 1+2 data

WP6: Analysis preservation and Open data
- Release of Run 1 LHCb data to CERN Open Data portal
- Guidelines and tools for analysis preservation
- LHCb use of CERN’s CAP and REANA

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WP1: Sprucing

In Run 3 event persistency is **customisable** depending on the Physics involved.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Event Size (kB)</th>
<th>Event Rate (kHz)</th>
<th>Rate Fraction</th>
<th>Throughput (GB/s)</th>
<th>Bandwidth Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FULL</strong></td>
<td>70</td>
<td>7.0</td>
<td>65%</td>
<td>0.49</td>
<td>75%</td>
</tr>
<tr>
<td><strong>Turbo</strong></td>
<td>35</td>
<td>3.1</td>
<td>29%</td>
<td>0.11</td>
<td>17%</td>
</tr>
<tr>
<td><strong>TurCal</strong></td>
<td>85</td>
<td>0.6</td>
<td>6%</td>
<td>0.05</td>
<td>8%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>61</td>
<td>10.8</td>
<td>100%</td>
<td>0.65</td>
<td>100%</td>
</tr>
</tbody>
</table>

In Run 2 - 32% of physics events went to TURBO

With no changes to Run 2 model trigger output (to tape) is 17.4GB/s!

40% more physics must move to Turbo in Run 3

Huge migration effort
For physics left in FULL stream - **Sprucing:**

- Utilise cheap **tape storage** for bulk of bandwidth (FULL stream)
- Perform central offline slimming/skimming

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### WP1: Sprucing

<table>
<thead>
<tr>
<th>Output data volume</th>
<th>Turbo physics fraction</th>
<th>Physics channels left in FULL</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 GB/s</td>
<td>73%</td>
<td>EW, high PT, (semi)leptonic and some hadronic B-physics, leptonic charm decays and general LFV searches</td>
</tr>
<tr>
<td>7.5 GB/s</td>
<td>87%</td>
<td>EW, high PT, some leptonic B-physics, some LFV searches and leptonic searches</td>
</tr>
<tr>
<td>5 GB/s</td>
<td>99%</td>
<td>None</td>
</tr>
</tbody>
</table>

**Sprucing**

A further offline stage of data reduction/selection between **tape** and **disk** storage when HLT2 line throughput is too large to go straight to disk.

Utilise same selection framework as HLT2

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**Default Turbo model**

**Sprucing model**

Data to tape at 10GB/s
Data to disk at 3.5GB/s

**Analysis production**

70% of physics

Topological, inclusive triggers, datamining

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Baseline
WP2 : Analysis productions (AnaProd)

In Run 1 + 2 analysts created nTuples individually from data on disk using Ganga... does not scale well for Run 3

- 1000s of faulty jobs can be submitted instantly (10% of user jobs fail)
- Time consuming - O(weeks) for Run 1 + 2 tuples - failed jobs re-submitted manually by user
- No analysis preservation infrastructure

Analysis productions submit nTupling jobs **centrally using DIRAC transformation System** (AnaProds already in use for legacy data)

- Does not require analyst to babysit grid jobs
- Options tested automatically upon push to GitLab (CI). Final approval must be given from PAWG liaisons
- Job details/configuration/logs automatically preserved in LHCb bookkeeping/EOS
- Automated error interpretation/advice
- Results displayed on webpage
WP2: Analysis productions (AnaProd)

See slide 10

Options tested on GitLab CI

Job configuration/logs preserved in bookkeeping

Automated error interpretation

Write options files locally

Push to GitLab

Tests results look good?

Yes

No

Request review from DPA/RTA liason

Liaison merges?

Yes

CI submits production requests

nTupl

defaults:
application: BaViinci/v45r5
ws: Chare
automatically configure: yes
infant:
- dylan.white@cern.ch
options:
- ntuple_options.py
output: DB2KX, ROOT

2016_MapDown_PromptMC_DB2KX:
input: 
- bk_query.py
- /P/2016/Beam500GeV-2016-MapDown-Nu1.6-25ns-Pythia8/Simu

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WP3 : Offline analysis tools

In Run 1+2 nTuples used “TupleTools” from DaVinci (user analysis) application

- “TupleTools” create and save variable branches for typical use cases eg. TupleToolTrackInfo
- Very easy to implement but adds lots of redundant branches - can easily save 500+ variables
- 500GB - 10TB of data for a single Run 1+2 analysis - nTuples tend to be only used for one analysis

For Run 3 complete redesign of DaVinci framework - **FUNTUPLE**

- Same thread-safe functors as in HLT2/Sprucing used to create light-weight nTuples
  - Consistency between Online and Offline selections/tools/algorithms
- Analyst has full control over exactly which variables for which particles are persisted in nTuple
- AnaProds will run analysts’ DaVinci options
WP4 : R&D Innovative analysis techniques

Think tank for innovative analysis techniques and exploitation of new analysis facilities with heterogeneous computing resources (GPU/CPU/FPGA)

Worldwide LHC Computing Grid (WLCG) consists of ~ 1M CPU cores over 170 sites

- Most sites have no GPUs yet - push towards High Performance Computing (HPC) centers providing large GPU resources
- Potential to utilise LHCb’s HLT1 GPU farm during detector downtime

Need development such that significant LHCb payloads can run on GPUs

- Use advanced algorithms such as Generative Adversarial Networks (GANs) to train models describing LHCb sub-detector response - GPUs speed up GAN training - Ultra-fast simulation
- Users using GPUs for analysis, e.g. TensorFlow for model fitting (Zfit) - particularly for complex amplitude analysis models with large statistics

First investigations into use of Quantum Machine Learning for jet tagging (see backup)
WP6: Analysis preservation and open data

Run 1 LHCb data to be released on [CERN Open Data portal](https://www.cern.ch/)

- Development of Open Data nTuple wizard
  - Auto-generates options from intuitive user input - no knowledge of LHCb software required
  - Launches AnaProd (See slide 8-9)
  - Returns nTuple to user
- Much smaller storage and bandwidth requirements on Open Data Portal
- Will be used by collaboration members to analyse Run 1+2 data

Analysis preservation has been in place at LHCb since 2017 - building on this

...analysis code should be preserved in a long-term archive such as a physics analysis gitlab group, the input ntuples should also be preserved in a long-term archive (EOS) and sufficient documentation to enable a (technically competent) LHCb member to run the code in a standard environment such as lxplus should be included with the code.

- Developing tag-based access to AnaProd output removing need for copying files/hard coding paths
- Support for snakemake (significant adoption in LHCb) in REANA
Summary

- LHCb will have to process data offline an order of magnitude larger than in Run 2 in 2022.
- LHCb is progressing well to meet the Offline demands that run 3 will bring, coordinated by the DPA project.
Backup
WP4: R&D Innovative analysis techniques

Quantum Machine Learning model for $b$ vs $\bar{b}$ jet tagging

- Quantum Circuit with parameterized gates
- Variables from jet particles encoded in a quantum state
- The state is processed by trainable quantum gates
- Measurements on the final state are mapped to labels ($b$ or $\bar{b}$)
- Parameters (of the gates) are optimized via a Gradient Descent minimization of a cost function (training)

For more information see PyHEP 2021 talk

Quantum models can allow the study of correlations among particles inside the jet meaning insight on jet substructure and better identification!