FROM COLLISIONS TO PHYSICS
- And how to get to publication -

Janina Nicolini

Goal of the lesson

DST vs mDST files

Trigger stages

Prescaling

Online selection

Generator level simulation

Stripping (campaign)

?

Analysis flow

Restripping

Offline selection

Filtering

Sprucing

Run 1 vs Run 2 vs Run 3 dataflow

Fullstreams vs Streams

Reconstruction level simulation

Analysis preservation

Goal of the lesson

DST vs mDST files

Trigger stages

Prescaling

Generator level simulation

Online selection

Stripping (campaign)

Will it be an awful lot of information?
Yes, but lots of links on the slides

Analysis flow

Offline selection

Restripping

Dataflow

Filtering

Run 1 vs Run2 dataflow

Analysis preservation

Fullstreams vs Streams

Reconstruction level simulation

How we perform analyses

Software designed to make common analyses as easy as possible.

So how and what do we do in analyses?

How we perform analyses

We usually measure:

- Production
- Decay properties

Of heavy flavour hadrons

→ short lifetime → what can we do?

How we perform analyses

We usually measure:

- Production
- Decay properties

Of heavy flavour hadrons

→ short lifetime → what can we do?

Use "stable" particles

Protons $p/\bar{p}$

Photons γ

Electrons $e^{\pm}$

Deuterons

Charged pions $\pi^{\pm}$

Charged kaons $K^{\pm}$

Muons $\mu^{\pm}$

How we perform analyses

First step reconstruction of properties.

Not single particle, but all charged tracks at the same time

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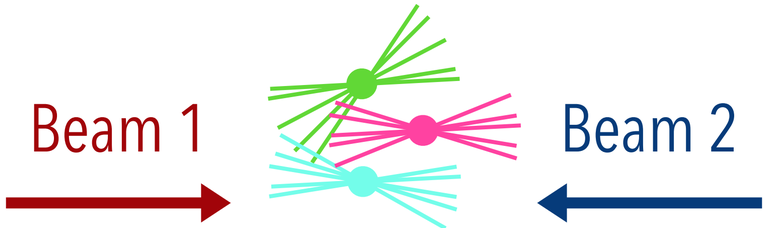


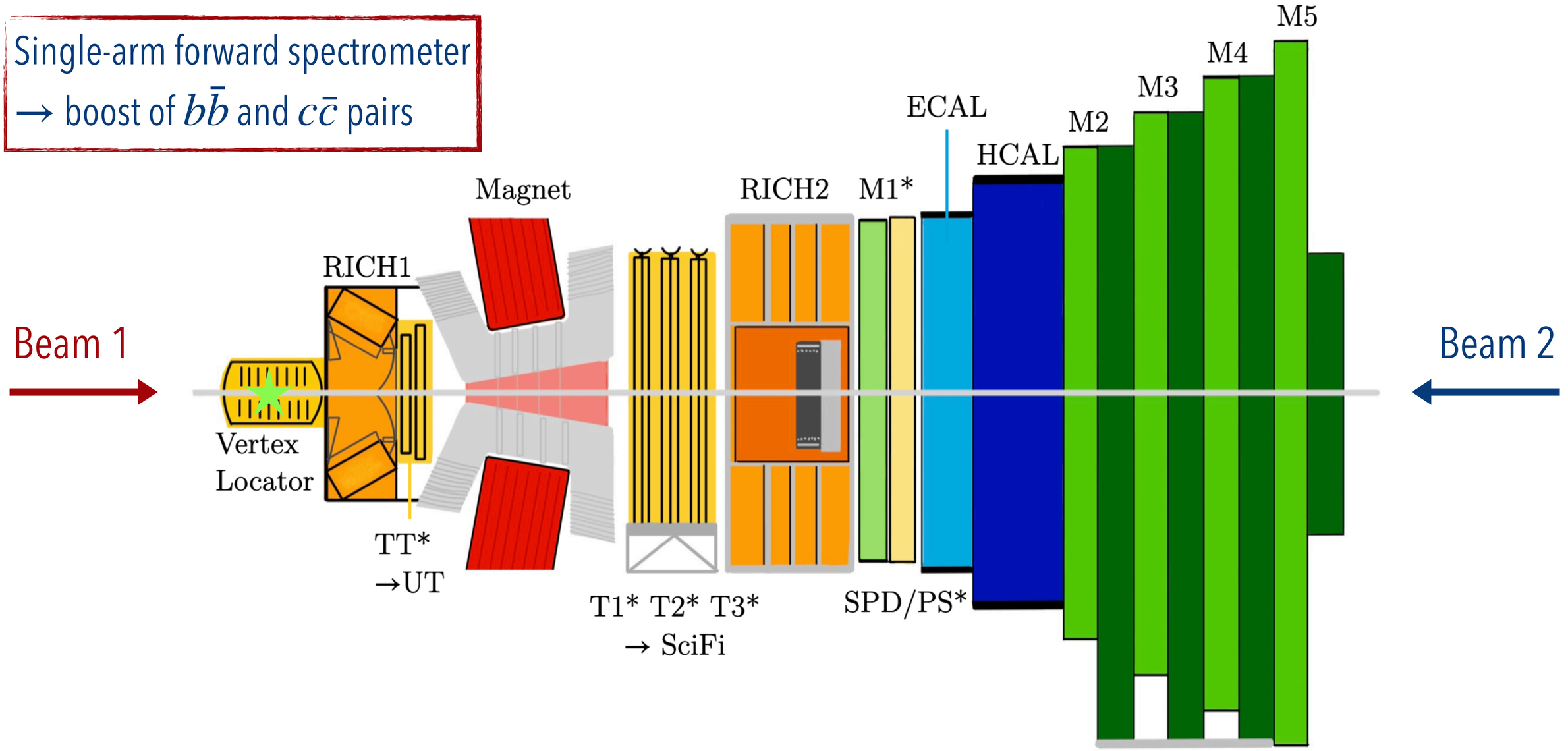
(Several) primary vertices

→ where protons collide

→ large number of tracks intersecting

Recap: The LHCb detector

Single-arm forward spectrometer
→ boost of $b\bar{b}$ and $c\bar{c}$ pairs

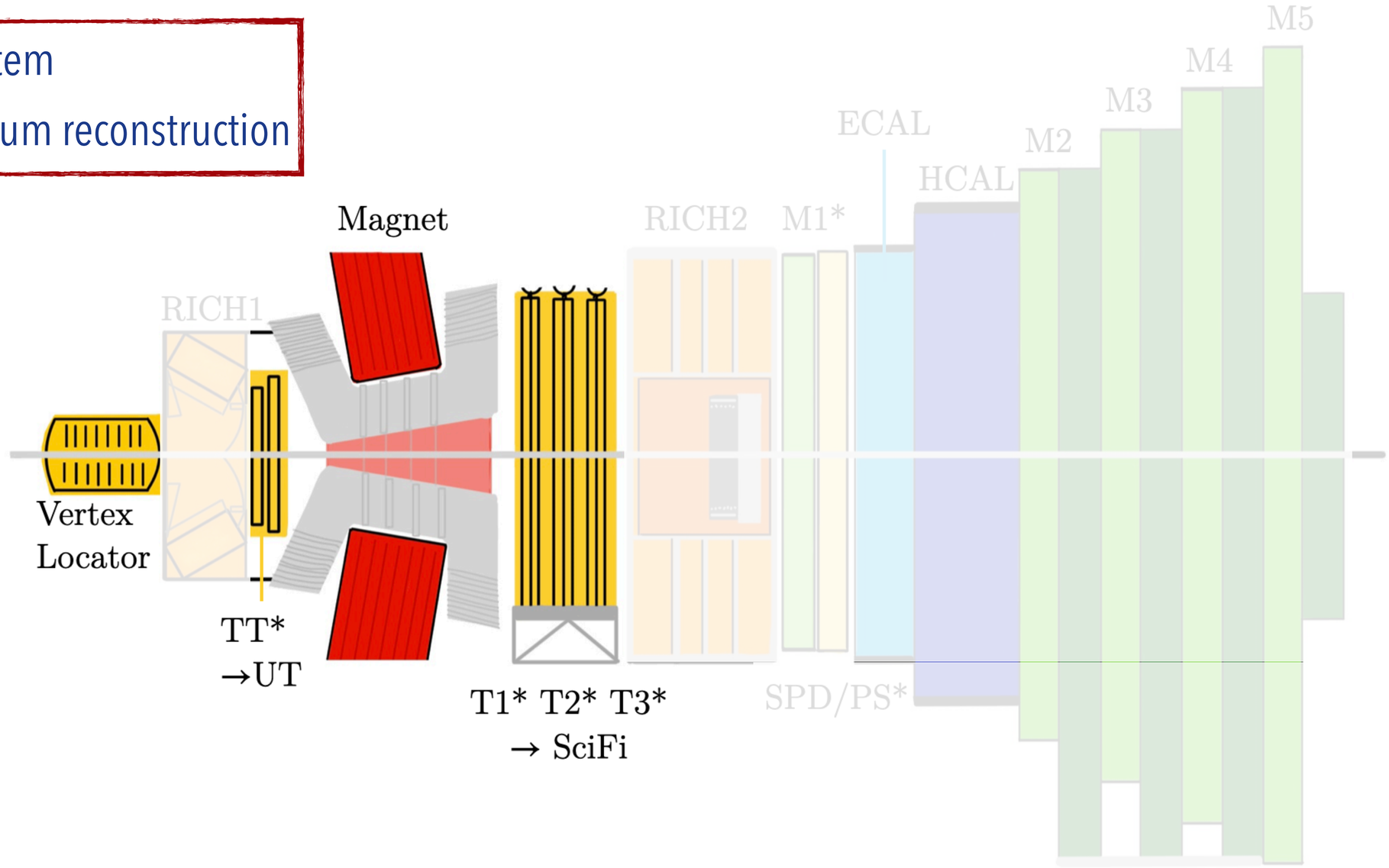


* replaced or removed
during Upgrade for Run 3

Recap: The LHCb detector

Tracking system

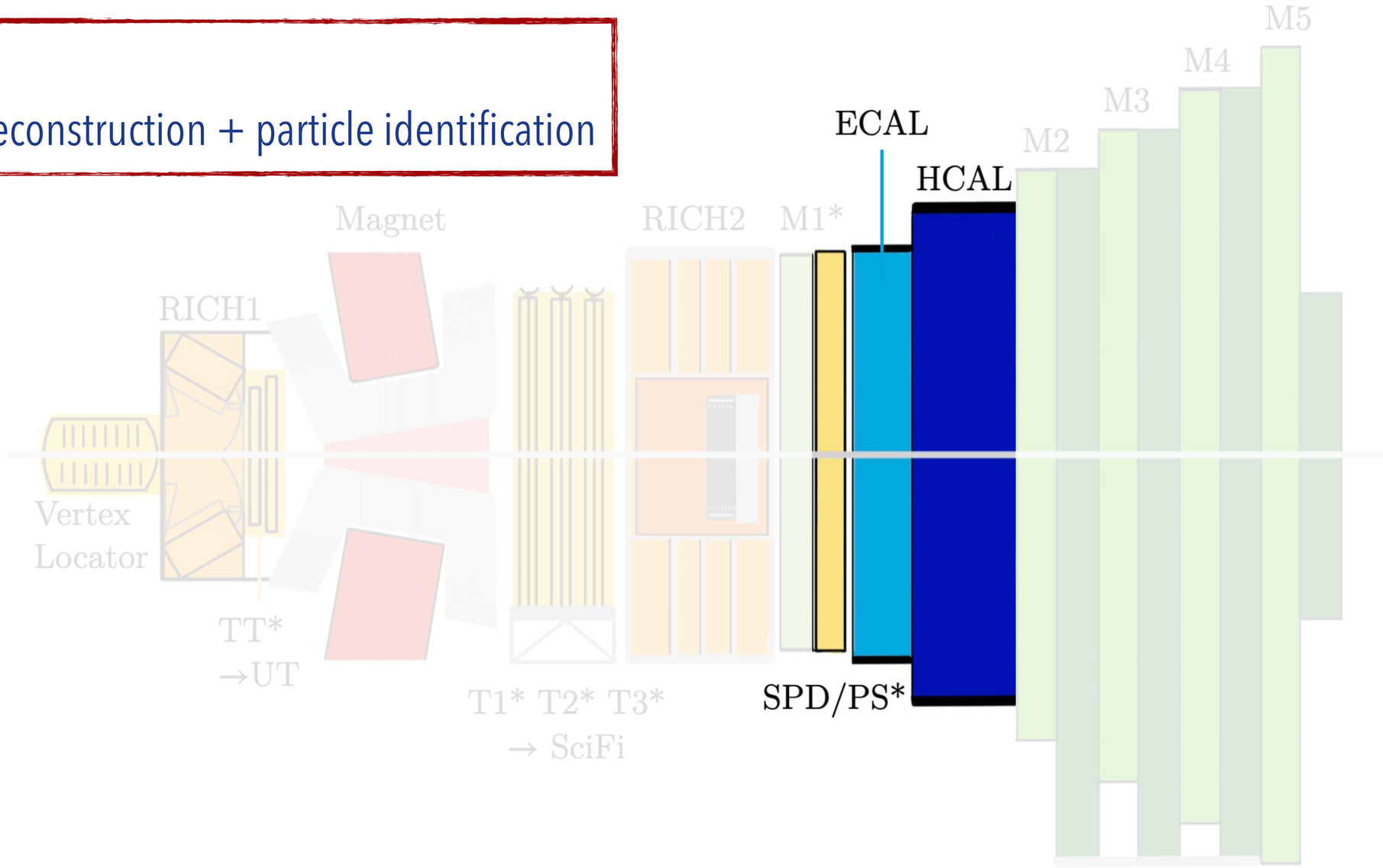
→ Momentum reconstruction



Recap: The LHCb detector

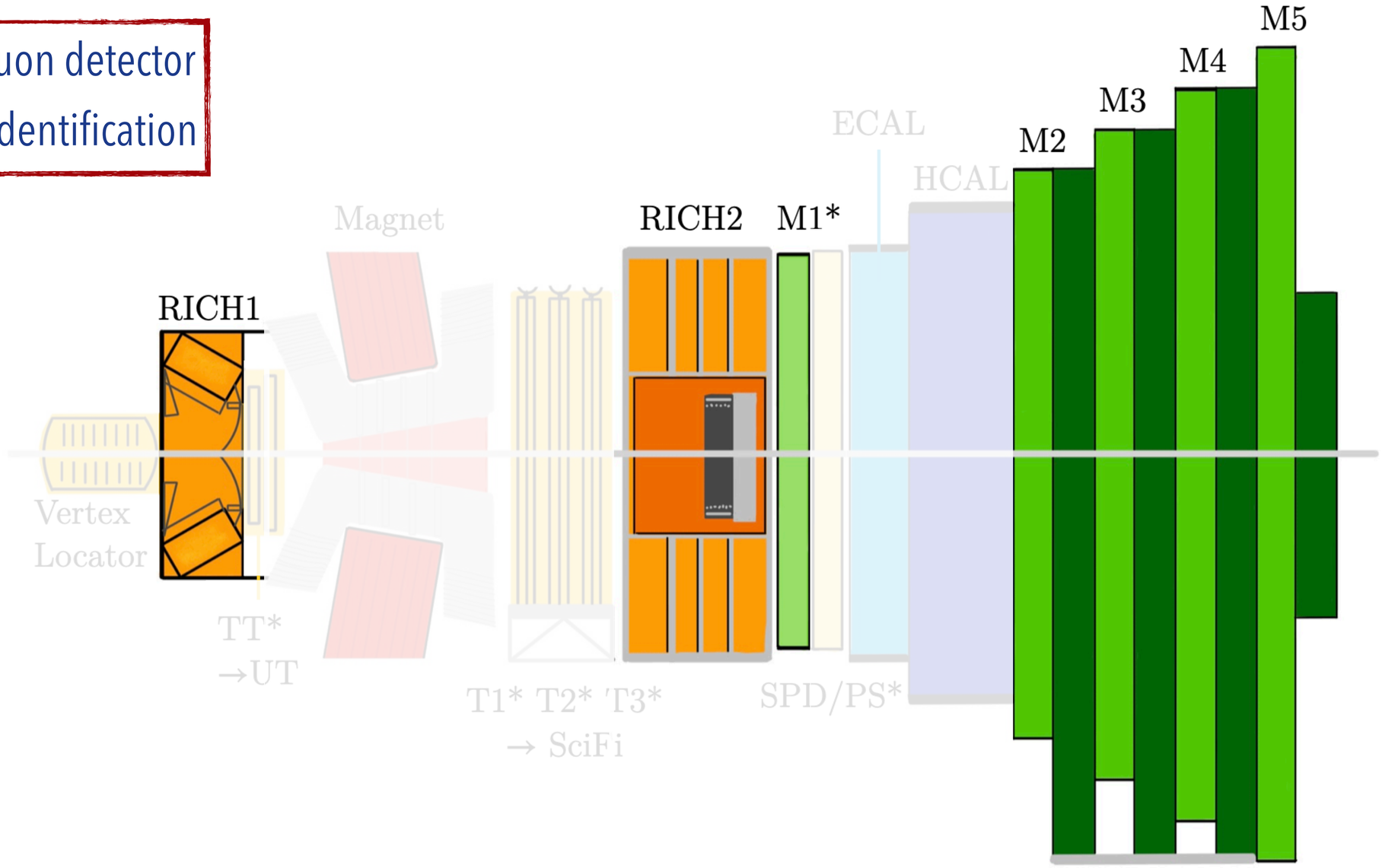
Calorimeter

→ Energy reconstruction + particle identification



Recap: The LHCb detector

RICH and muon detector
→ particle identification



How we perform analyses

Building decay candidates

Difficulties we encounter

- Contributions from detector effects
- "Ghost" tracks

  → combination of random hits
- Typical hundreds of tracks

→ statistical analysis of events

How we perform analyses

Building decay candidates

Reconstructing a $J/\psi \rightarrow \mu^+\mu^-$ decay

- Select suitable tracks created by reconstruction
- Create pairs of oppositely-charged tracks
- Fit each pair under the hypothesis the originate from a common point in space

How we perform analyses

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High momentum cut

Use probability of true muon

→called ParticleIDentification variable

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Distance of closest approach between two muons not exceed max value

Invariant mass required to be close to J/ψ

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DecayTreeFitter tool allows to perform fit in software

$\rightarrow \chi^2$ of fit can be used in selection

How we perform analyses

Creating J/ψ candidate from muon four-momenta

Reconstructing a $J/\psi \rightarrow \mu^+\mu^-$ decay

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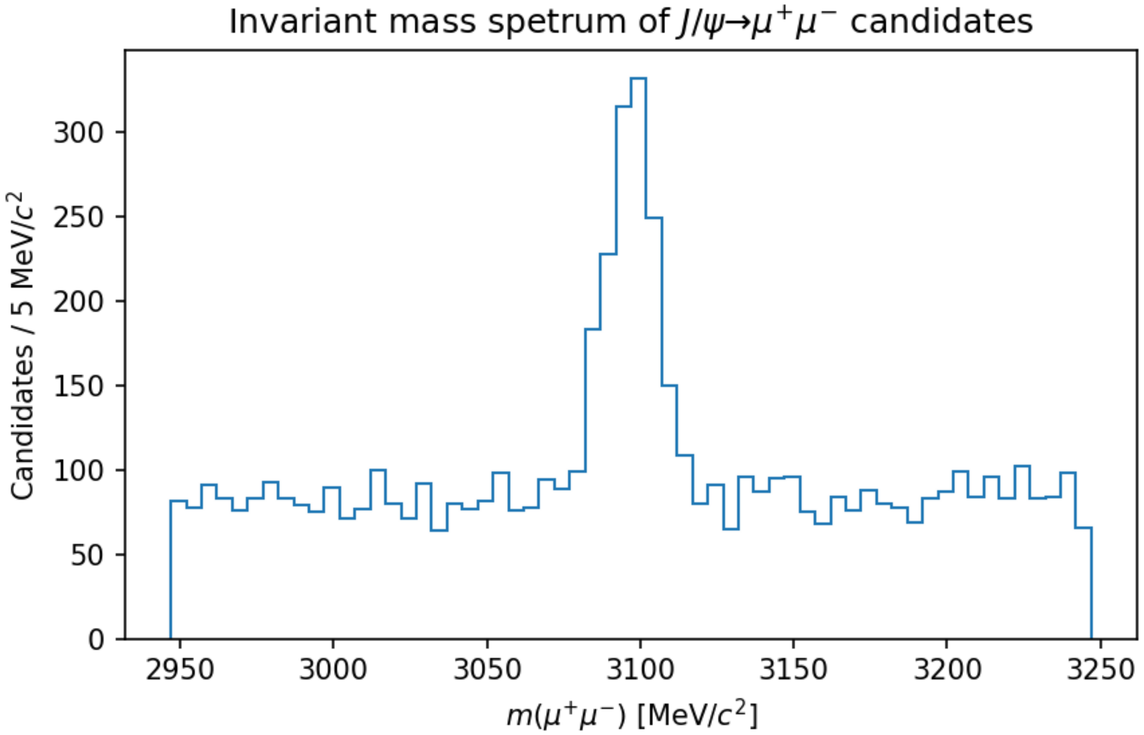
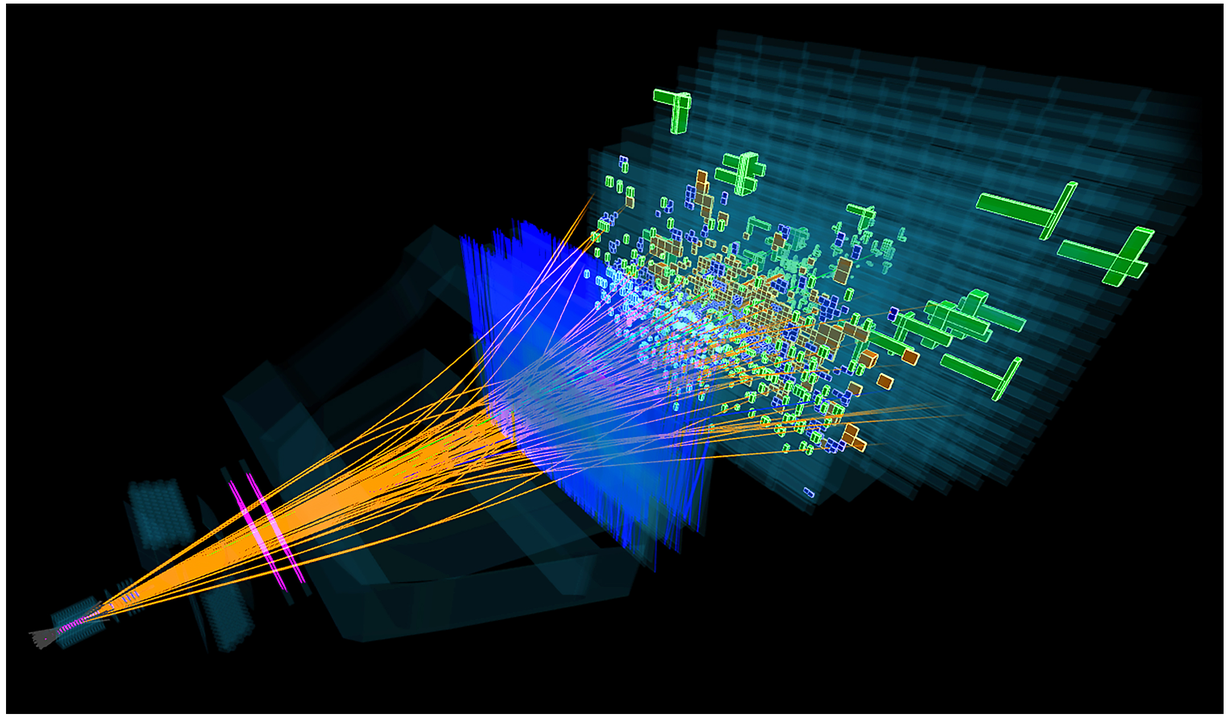


How do we decide what to save?

The LHC can provide a bunch crossing every 25ns.



Data rate is 40MHz*, but :

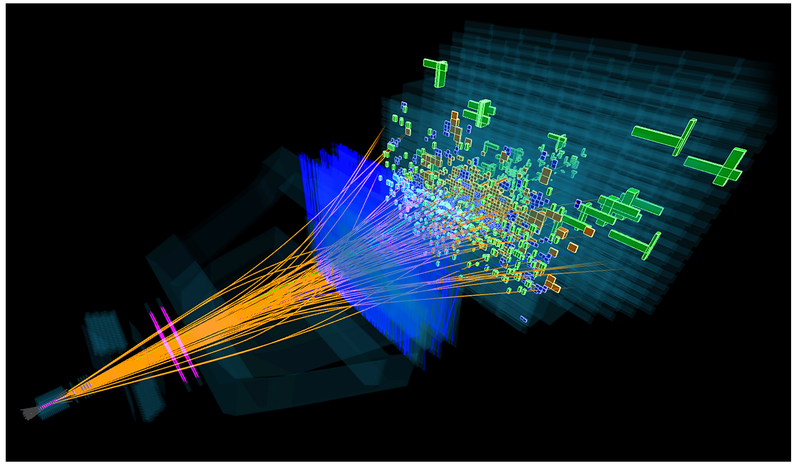
- Field Programmable Gate Array (FPGA) readout max. 1MHz
- Run 1: rate to storage max. 5kHz
- Run 2: rate to storage max. 12.5kHz

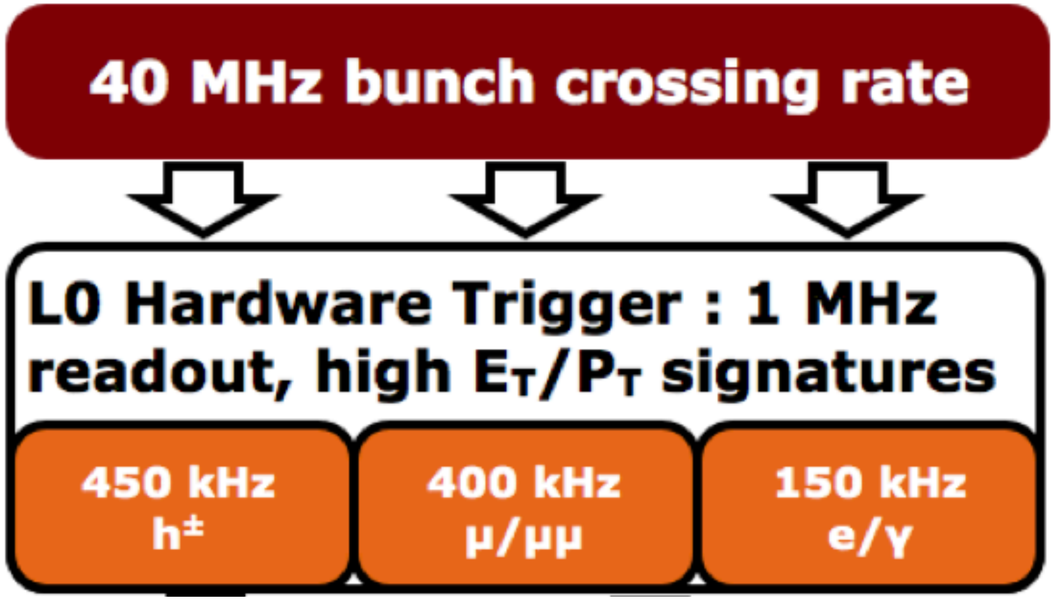
So we cannot save 1TB/s.

*Due to the filling scheme LHCb has a data rate of 30MHz

How do we decide what to save?

First a hardware trigger stage called L0.





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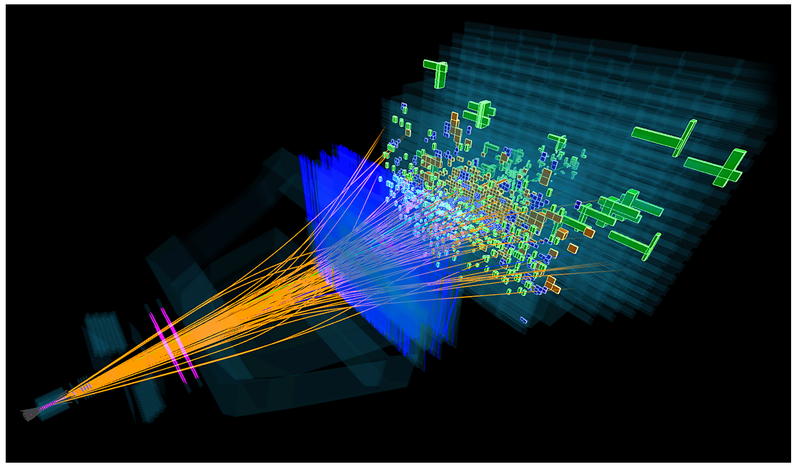
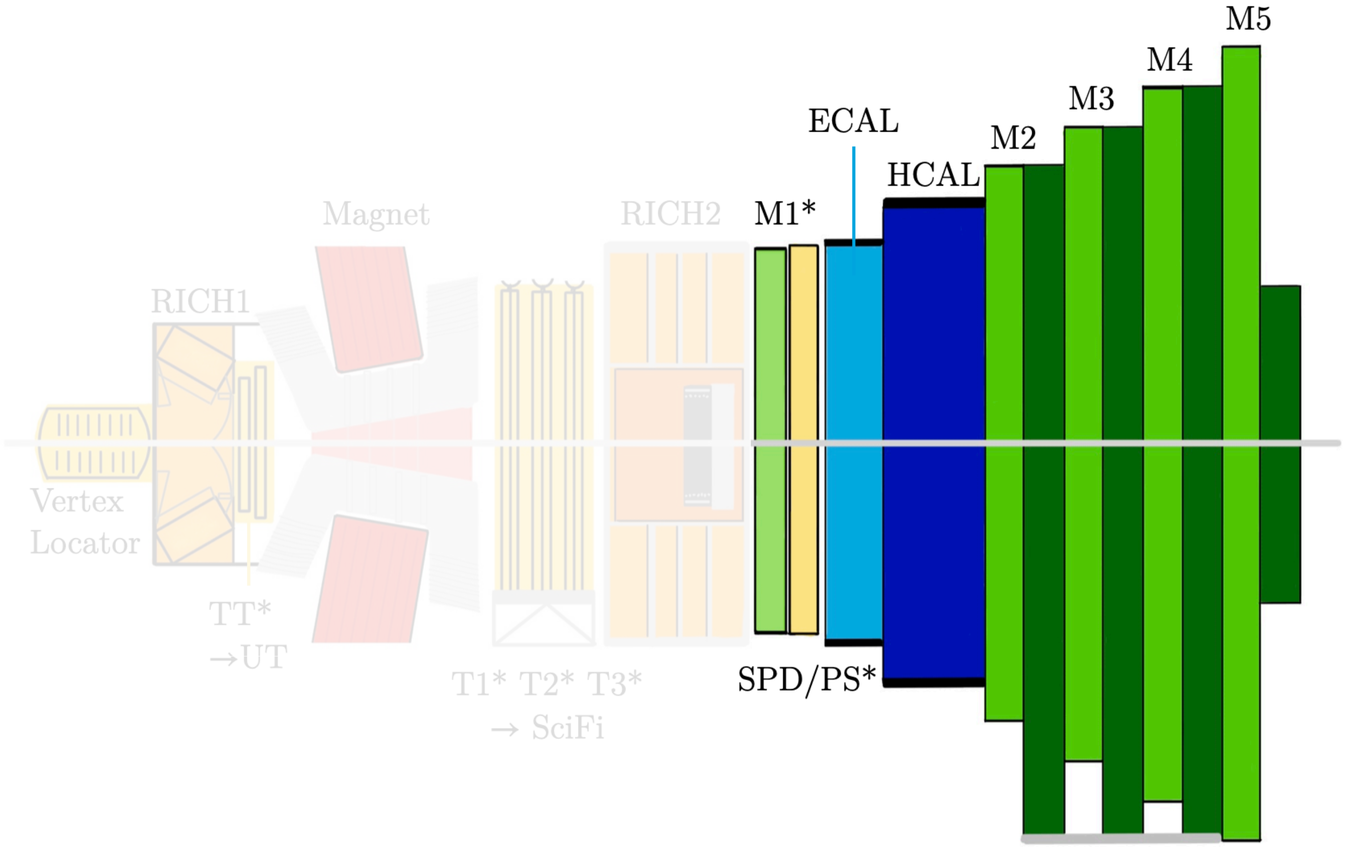




40 MHz bunch crossing rate

L0 Hardware Trigger : 1 MHz readout, high E_T/P_T signatures

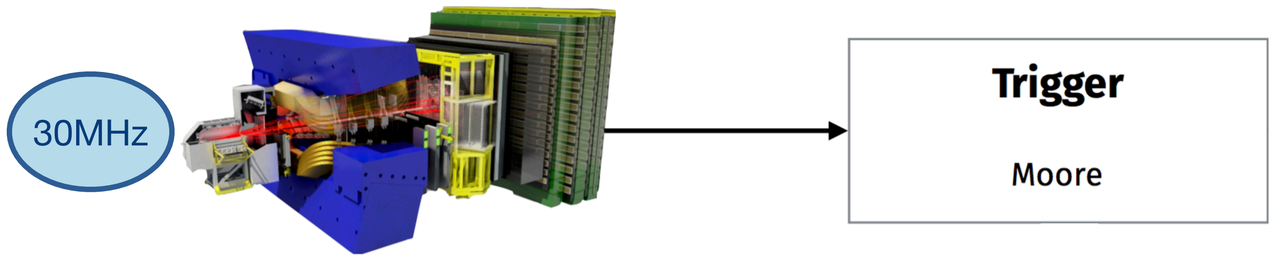
450 kHz $h^{\pm}$	400 kHz $\mu/\mu\mu$	150 kHz e/γ

Mainly two detector types firing:

- Hits in the muon stations
- Energy deposit in the ECAL and HCAL

Collision dataflow during Run 1

Second step of the online reconstruction.

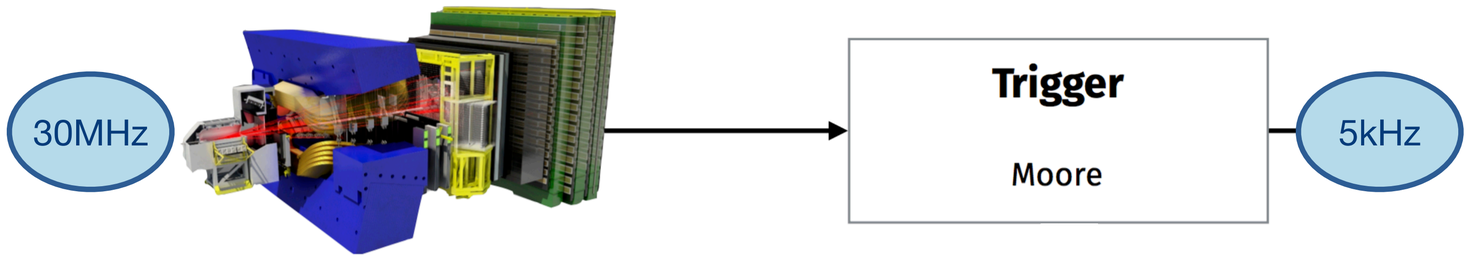


Next software stage called High Level Trigger

- HLT1: Adding tracking information
- HLT2: Adding RICH information
- Both run in Moore framework

Collision dataflow during Run 1

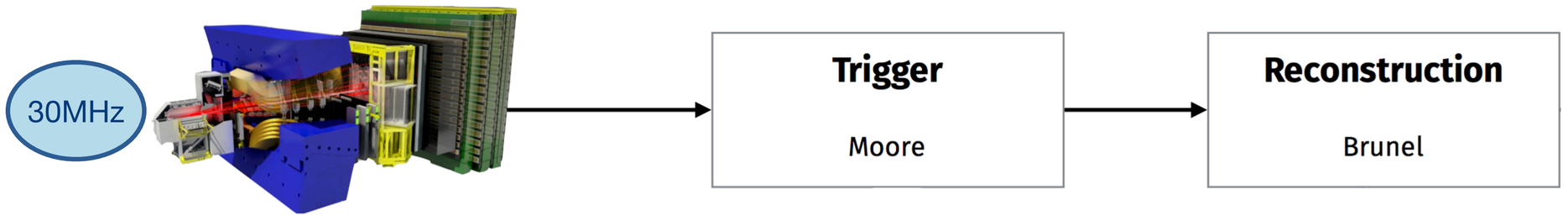
Online reconstruction done, but..



Fast trigger lead to worse resolution.
What do we do?

Collision dataflow during Run 1

The offline reconstruction

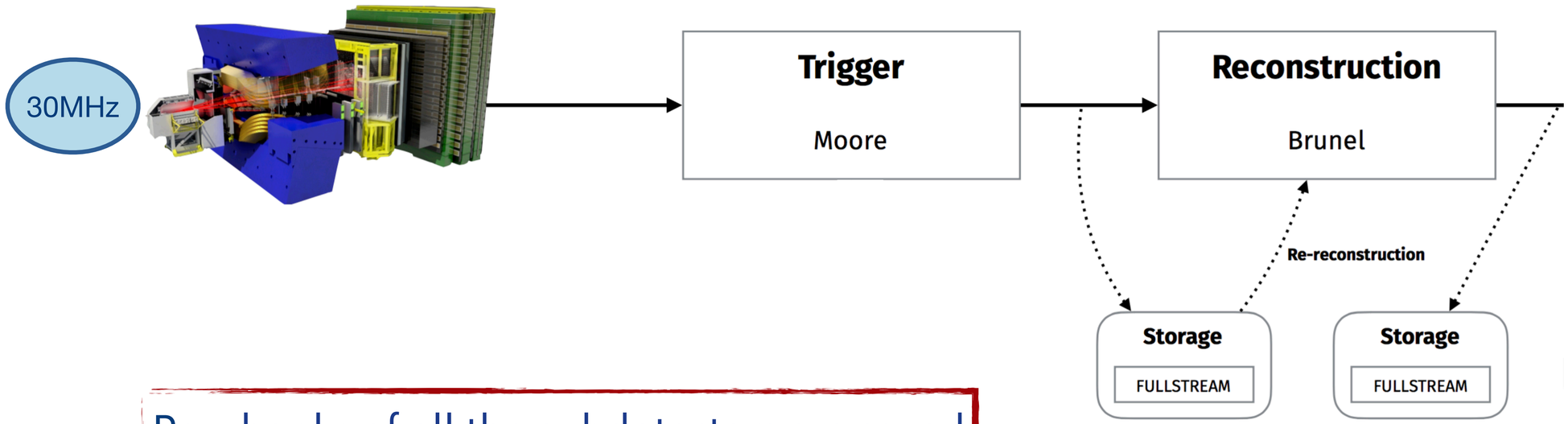


Improve reconstruction of:

- Tracks,
- Clusters,…
- Run in Brunel framework

Collision dataflow during Run 1

And storage of the data to tape



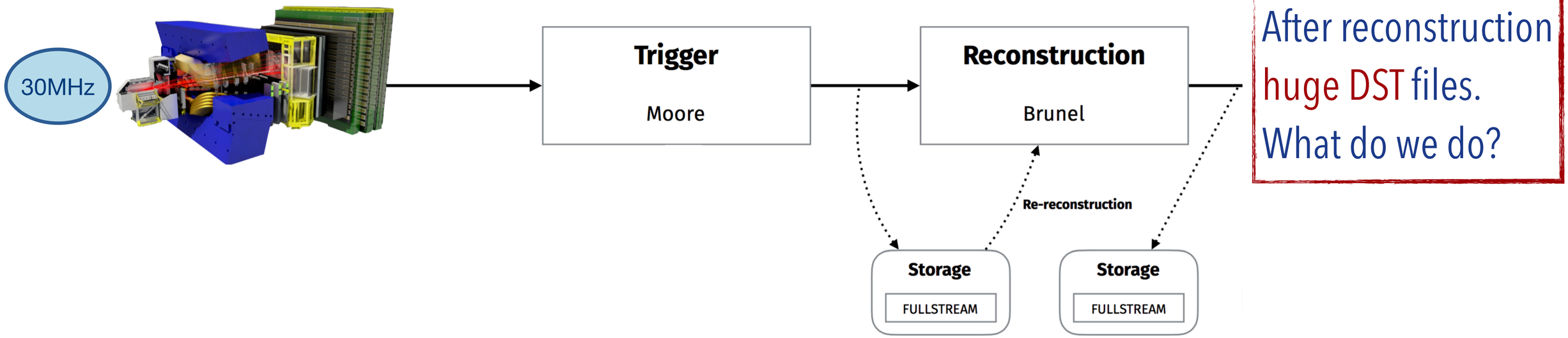
Raw banks of all the subdetectors are saved in FULLSTREAM

→ no further selection

→ Information stored in DST Files

Collision dataflow during Run 1

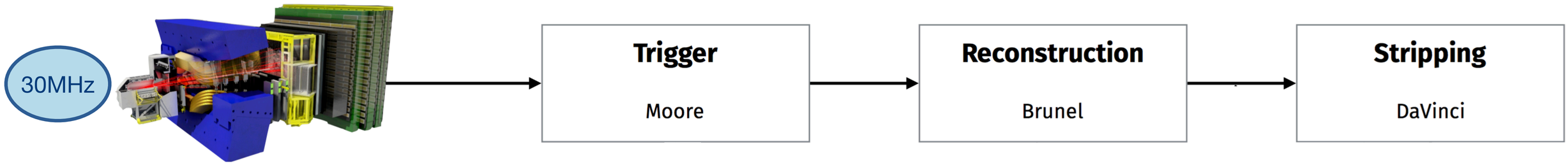
And storage of the data to tape



After reconstruction huge DST files.
What do we do?

Collision dataflow during Run 1

Reducing the file sizes

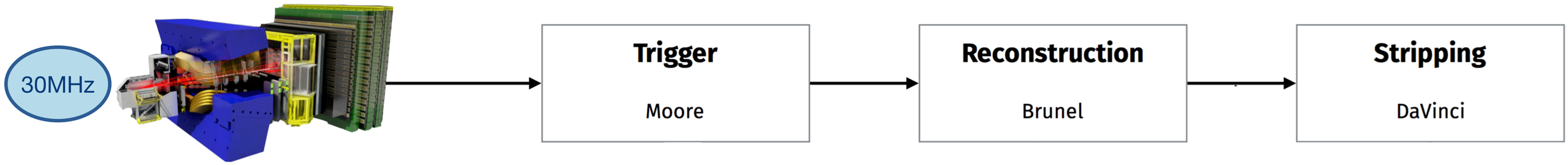


Selecting further with stripping lines

- Select certain decays based on signatures
- Exclusive: only one decay
- Inclusive: several decays combined
- Special lines: minimum-bias, BKG studies, …

Collision dataflow during Run 1

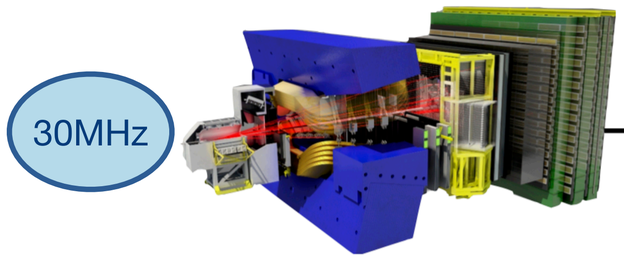
Reducing the file sizes



Special stripping lines

- Minimum-bias, BKG study
- Have very little selection → high rates
- Prescaling: save randomly only 0.1 [0.01] of the events
- Never use for other lines! Signal events are also lost!

Collision dataflow during Run 1



Trigger
Moore

Reconstruction
Brunel

Stripping
DaVinci

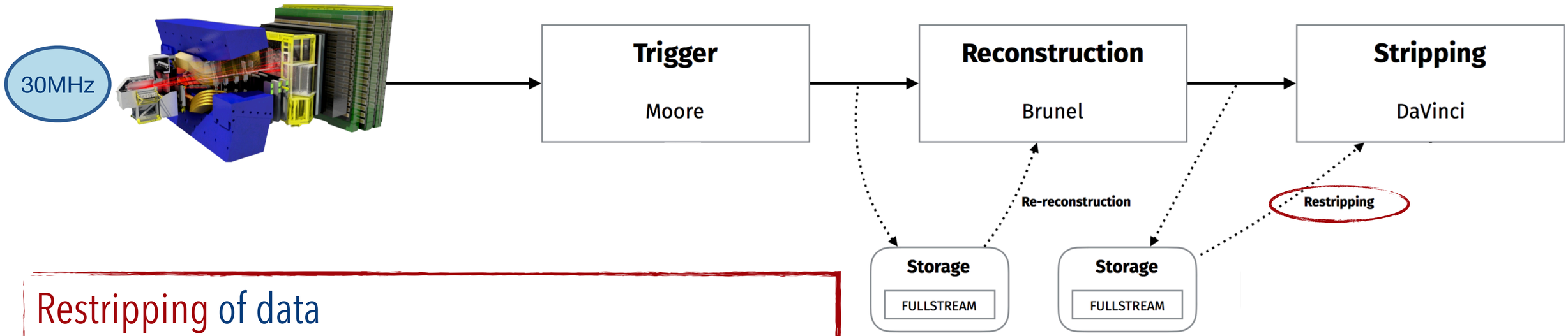
Storage
CHARM.MDST | DIMUON.DST | ...

Selecting further with stripping lines

- Several stripping lines organised in streams
- DST or mDST files (150 vs 50 kB/event)
- mDST only store tracks that passed selection, not whole event
- Run in DaVinci framework

Collision data Flow during Run1

What about new ideas?

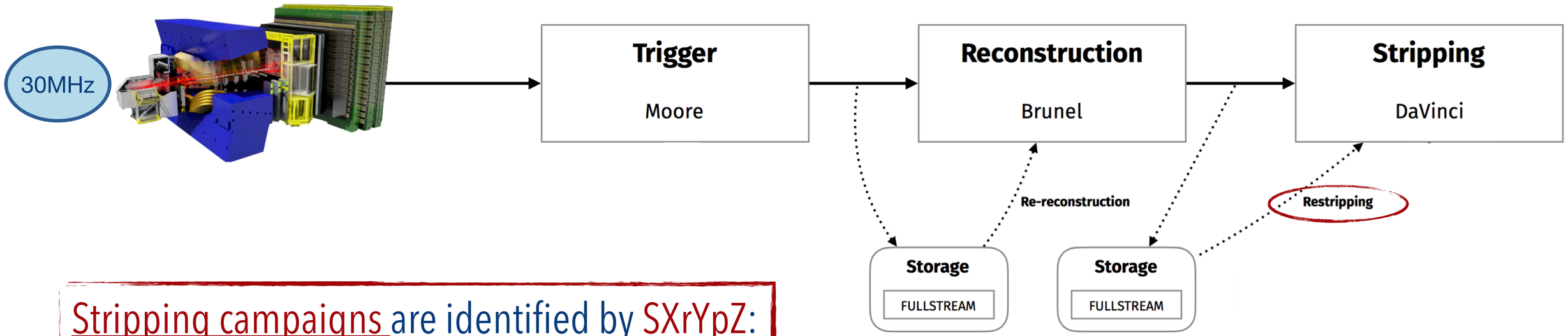


Restripping of data

- Allows to access new ideas with new lines
- Incremental restripping: only new/updated lines
- Full restripping: only done if bugs fixed e.g. in reco

Collision dataflow during Run 1

What about new ideas?

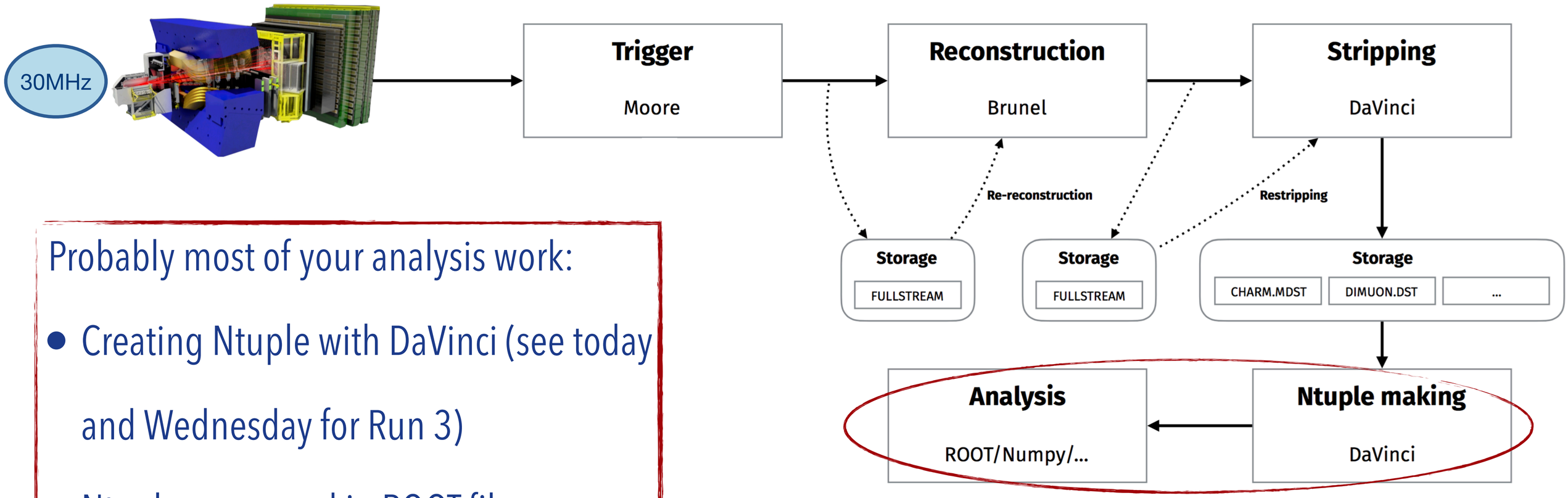


Stripping campaigns are identified by SXrYpZ:

- X: Full restripping campaign
- Y: data taking Year
- Z: incremental restripping

Collision dataflow during Run 1

And finally:

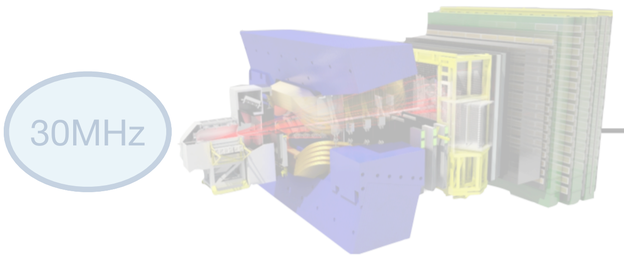


Probably most of your analysis work:

- Creating Ntuple with DaVinci (see today and Wednesday for Run 3)
- Ntuples are saved in ROOT files
- Your personal analysis

Collision data Flow during Run1

And finally:



Trigger
Moore

Reconstruction
Brunel

Stripping
DaVinci

Re-reconstruction

Restripping

Storage
FULLSTREAM

Storage
FULLSTREAM

Storage
CHARM.MDST
DIMUON.DST
...

Analysis
ROOT/Numpy/...

Ntuple making
DaVinci

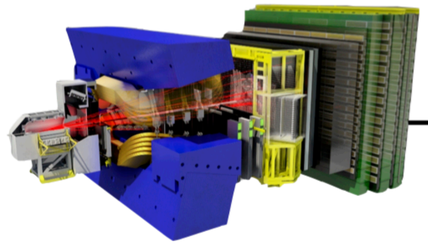
Probably most of your analysis work:

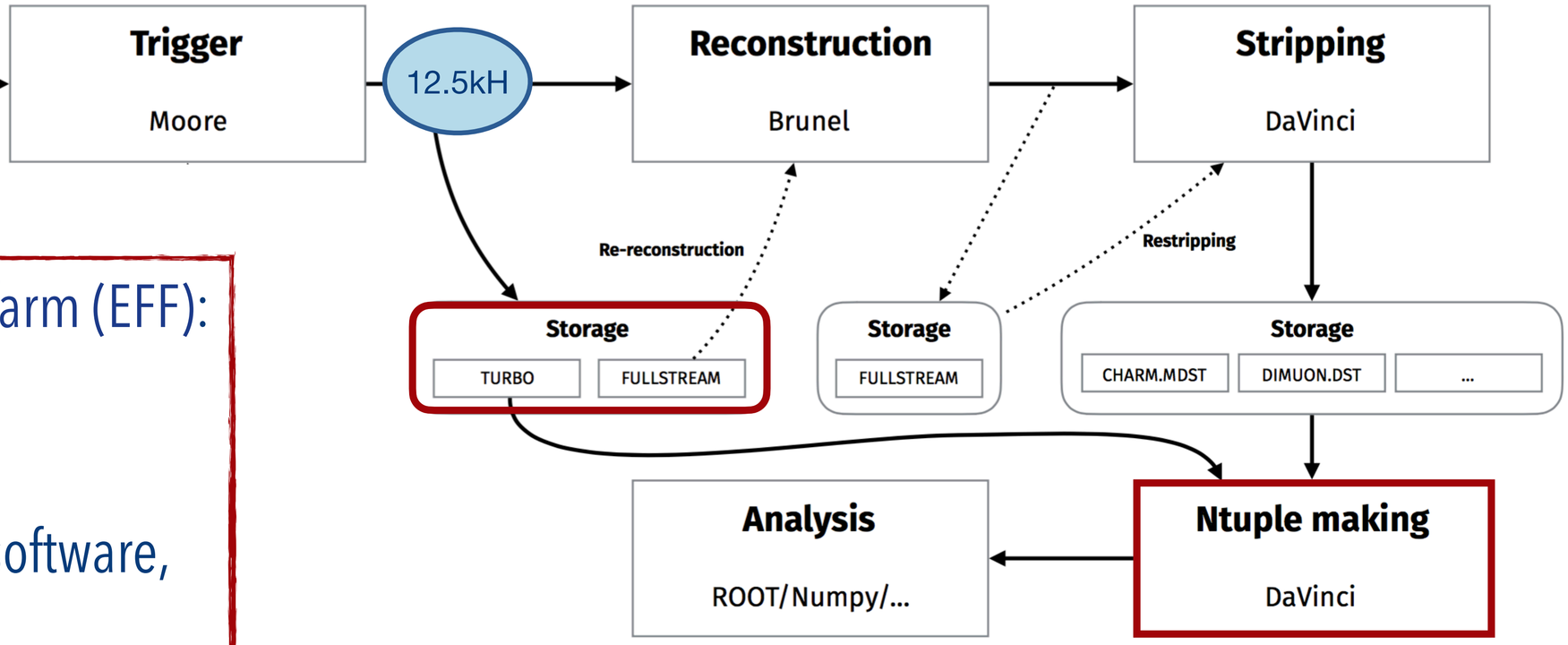
- Creating Ntuple with DaVinci (see today and Wednesday for Run 3)
- Ntuples are saved in ROOT files
- Your personal analysis

Lesson for DaVinci on TUE + WED

Collision dataflow during Run 2

What has changed?



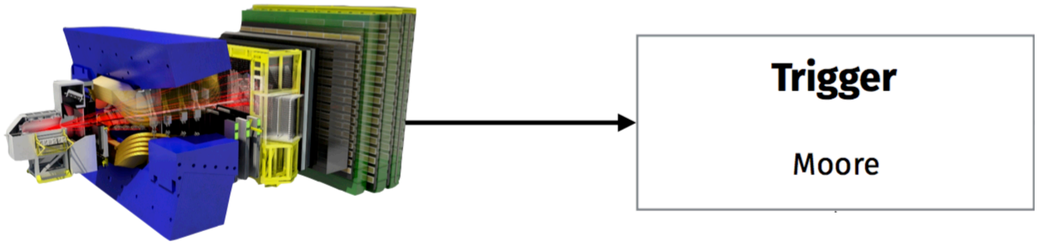


Upgrade of the event filter farm (EFF):

- HLT execution on EFF
- Improved hardware and software, automated calibration
- Full reconstruction now on HLT2!
- No offline reconstruction needed

Collision dataflow during Run 2

Some details about the time for high level trigger

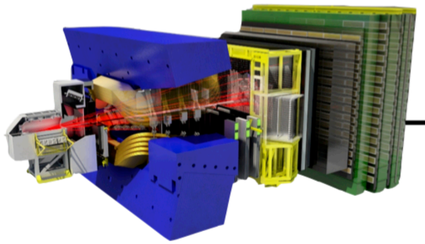


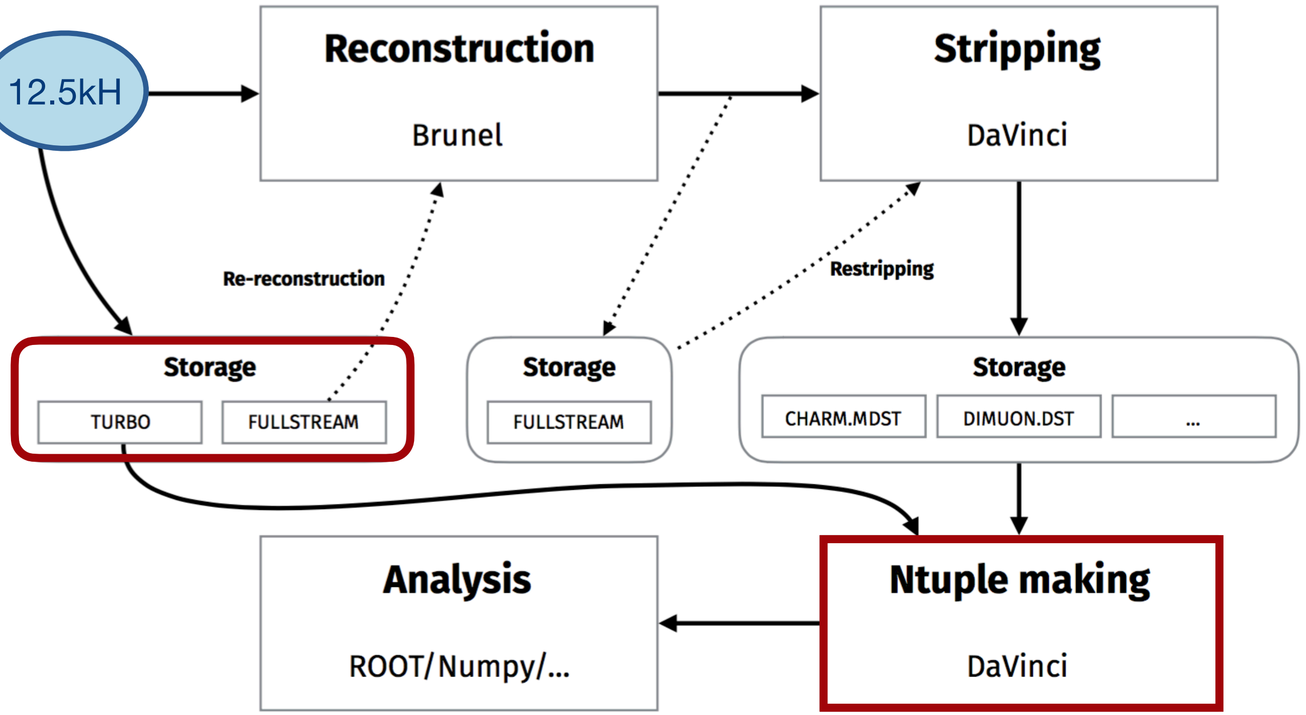
Next software stage called High Level Trigger

- HLT1: ms per event
- Alignment and calibration on 10Pb of buffer: mins/hours
- HLT2: full reconstruction takes hours

Collision dataflow during Run 2

Opens the option to bypass with Turbo



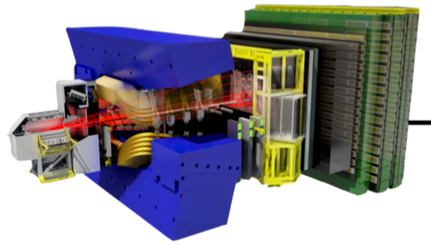


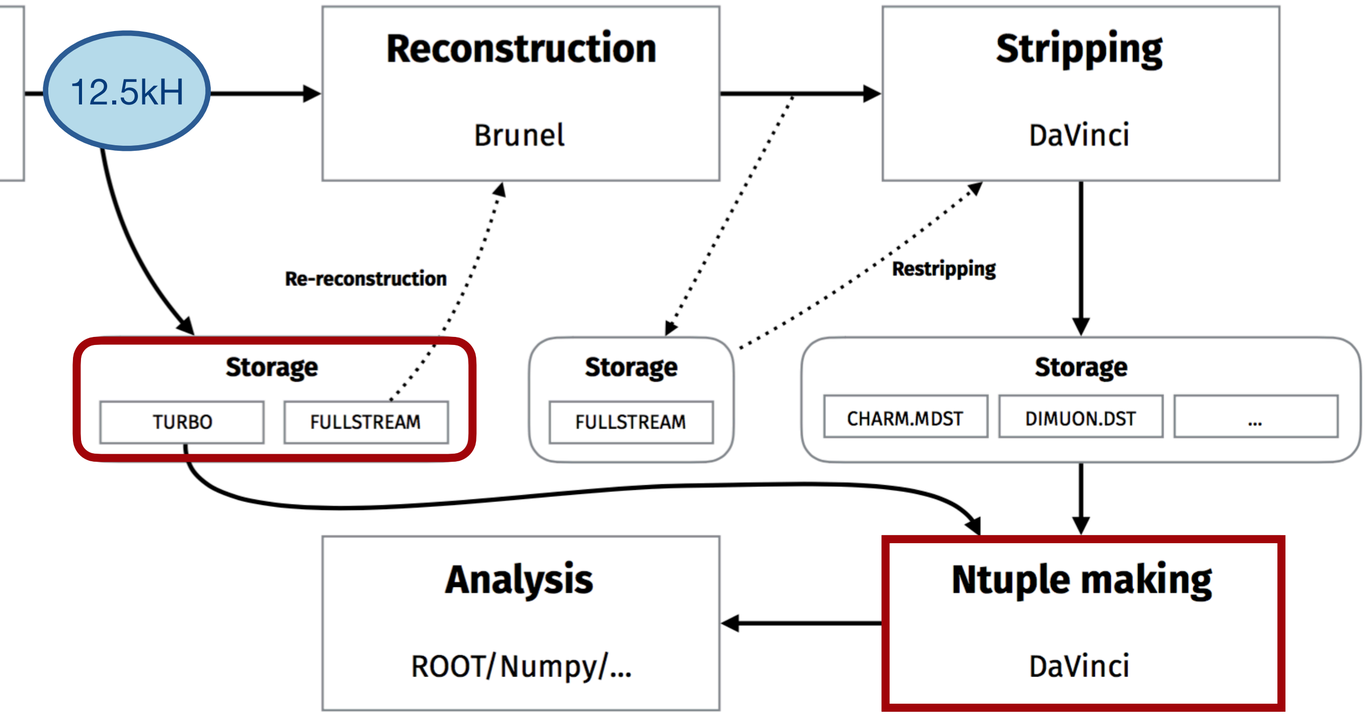
Still more events to store:

- Turbo stream: Saves only triggered tracks, rest of the event deleted
- Cannot be re-reconstructed
- For available lines ask trigger liaisons

Collision data Flow during Run2

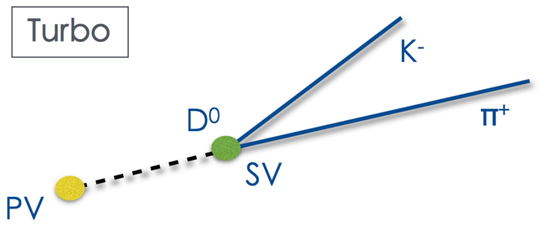
Opens the option to bypass with Turbo

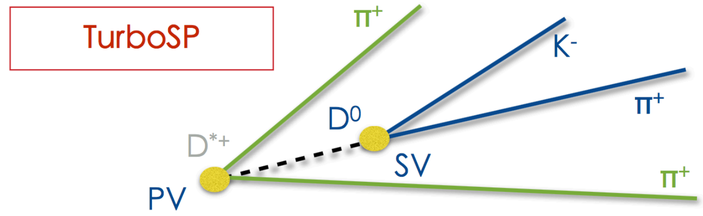




Three different Turbo definitons:

- Turbo: Saves only triggered tracks
- Turbo++: additional track information
- TurboSB: Free selection of additional information to save





Summary collision dataflow

Run 1

- HLT not accurate enough
- Offline Reconstruction always needed
- Maximum speed to disk 5kHz

Summary collision data flow Run 1 + 2

Run 1

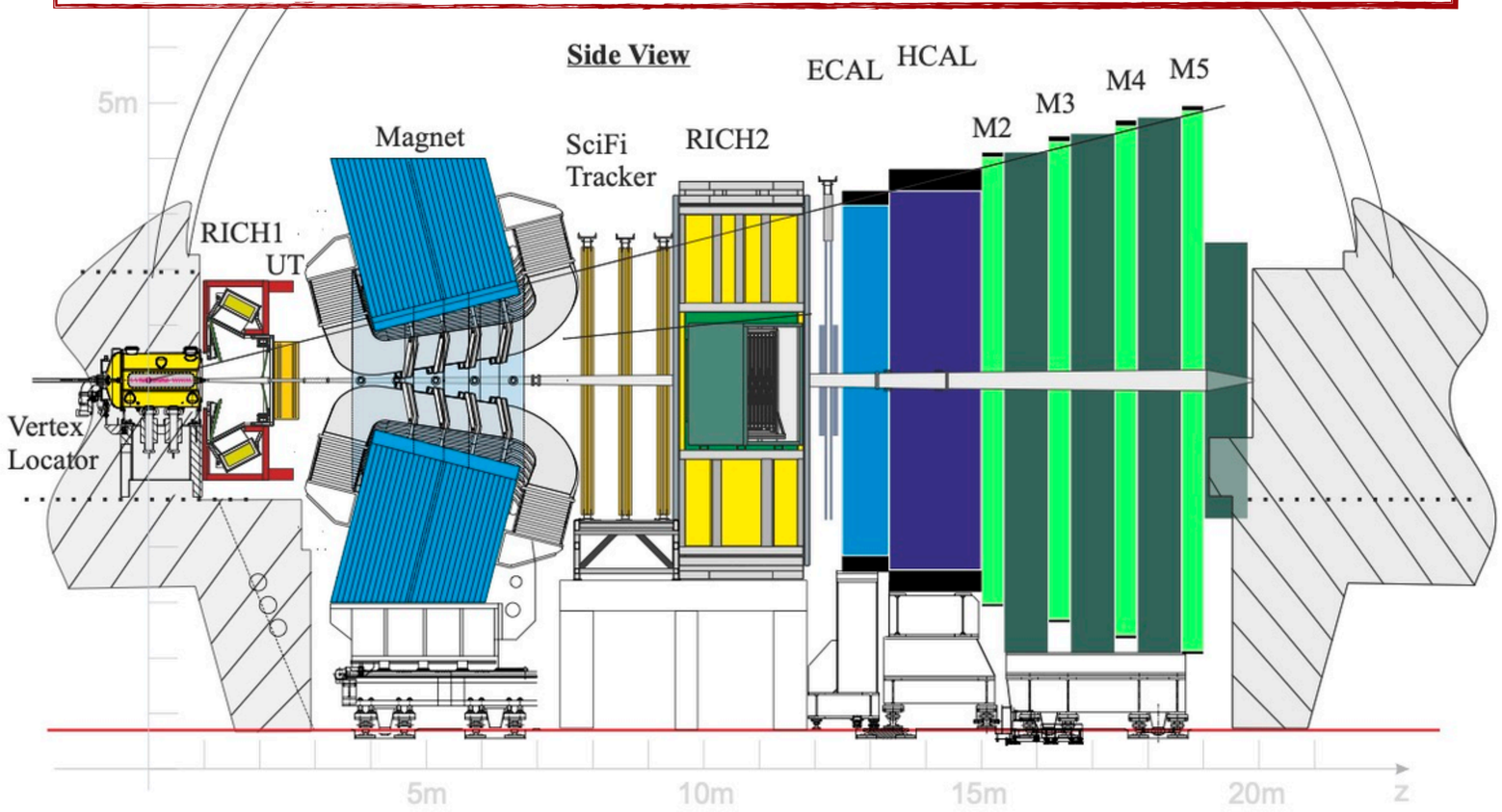
- HLT not accurate enough
- Offline Reconstruction always needed
- Maximum speed to disk 5kHz

Run 2

- Higher data rate
- HLT same accuracy without offline reconstruction
- Turbo Stream as bypass option
- Maximum speed to disk 12.5kHz

But okay we are in Run 3, so what changed?

A lot!

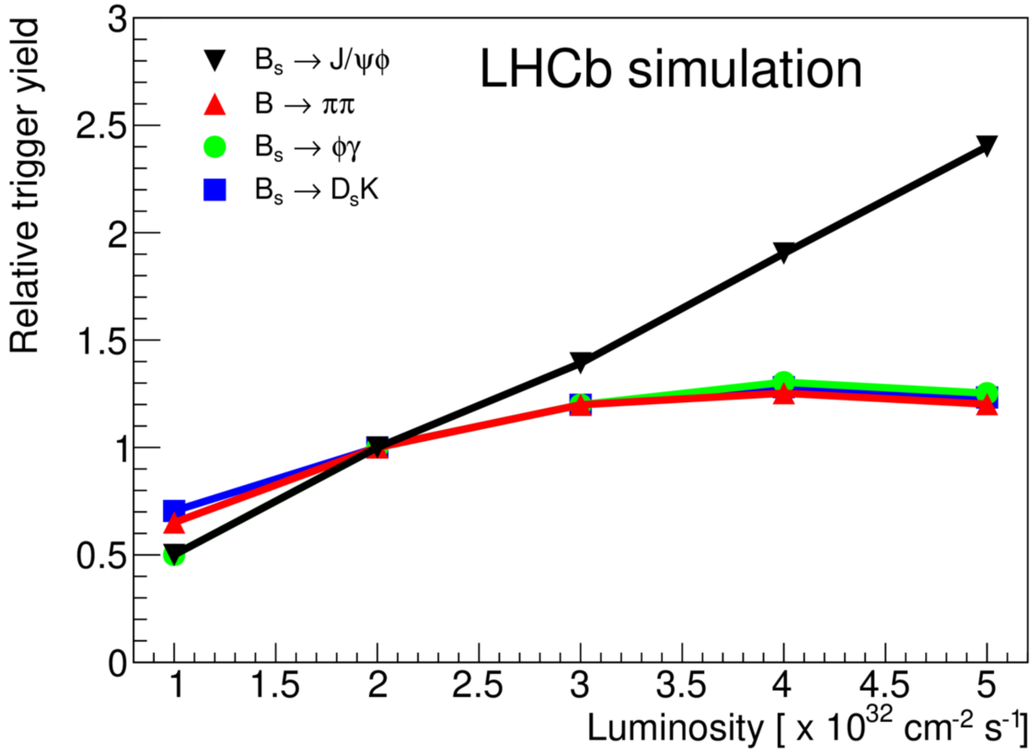


Why do we needed an Upgrade?

Increase precision by recording more luminosity

→ fast readout, high granularity, extreme radiation hardness

→ Limitation of hardware trigger stage



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Increase precision by recording more luminosity

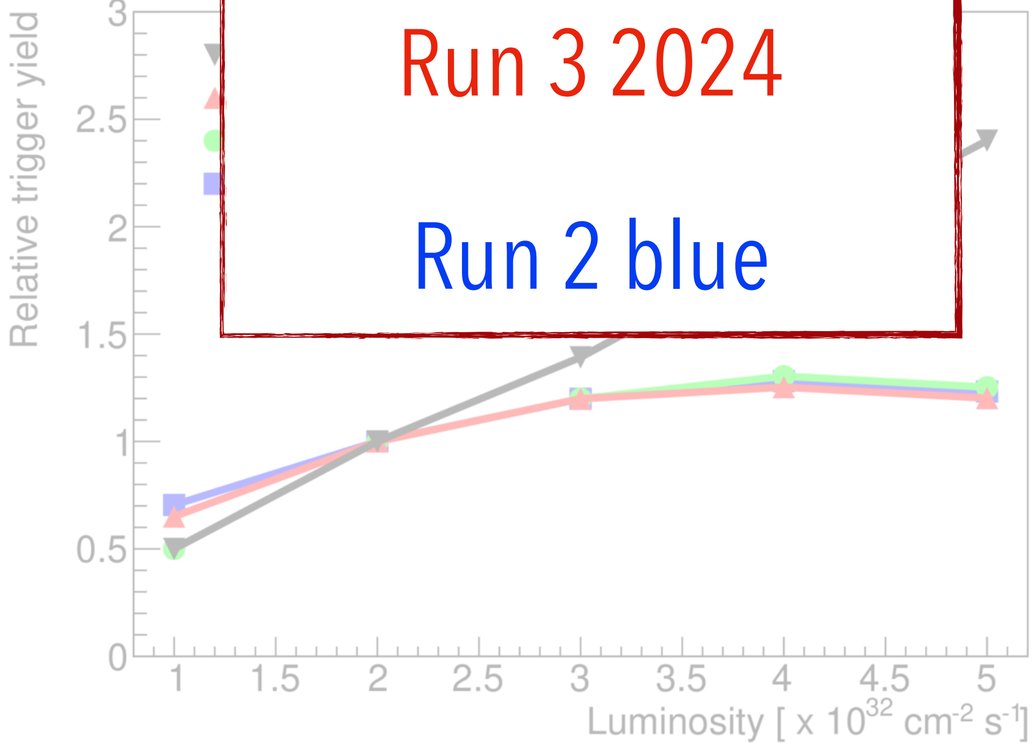
→ fast readout, high granularity, extreme radiation hardness

→ Limitati

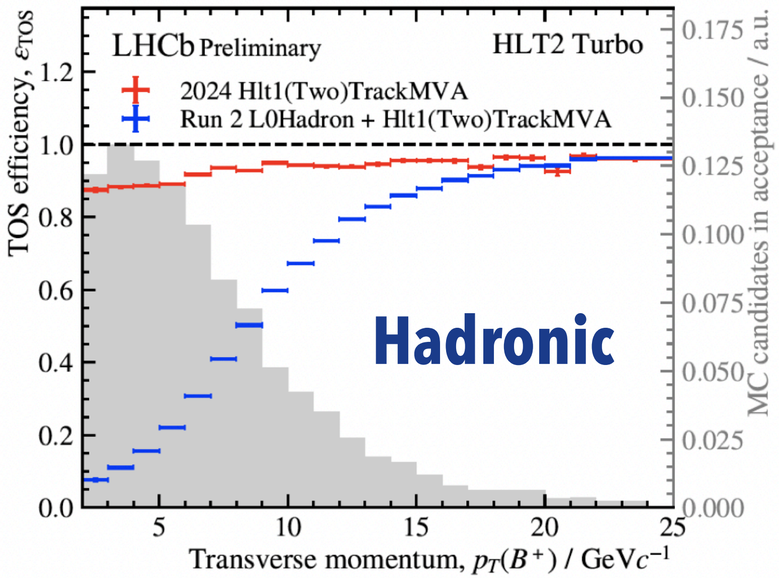
What did we achieve?

Run 3 2024

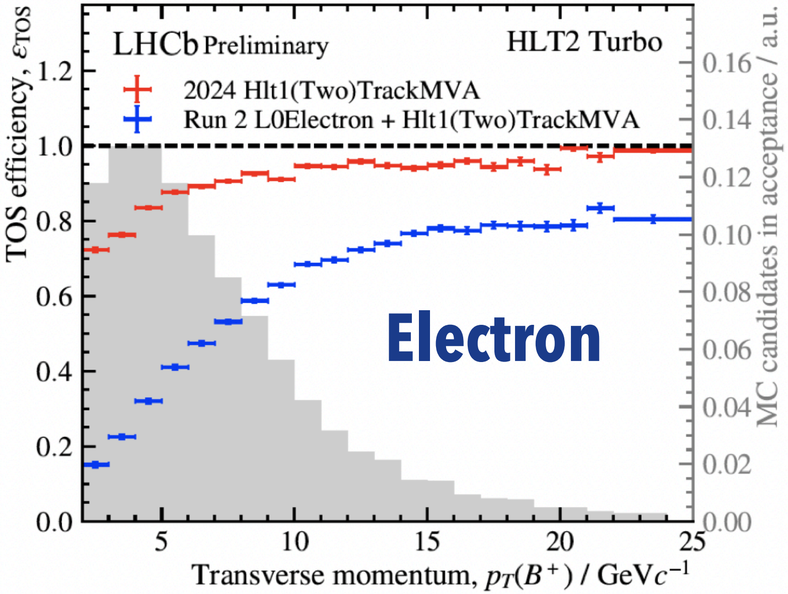
Run 2 blue



$B^+ \to D^0\pi^+$



$B^+ \to J/\psi(\to e^+e^-)K^+$

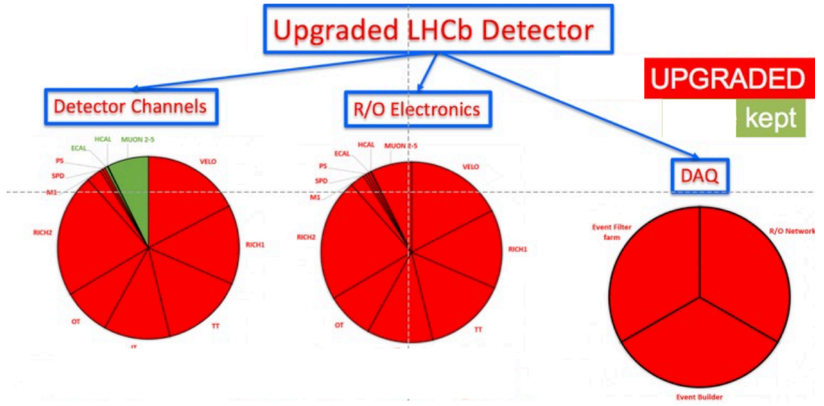


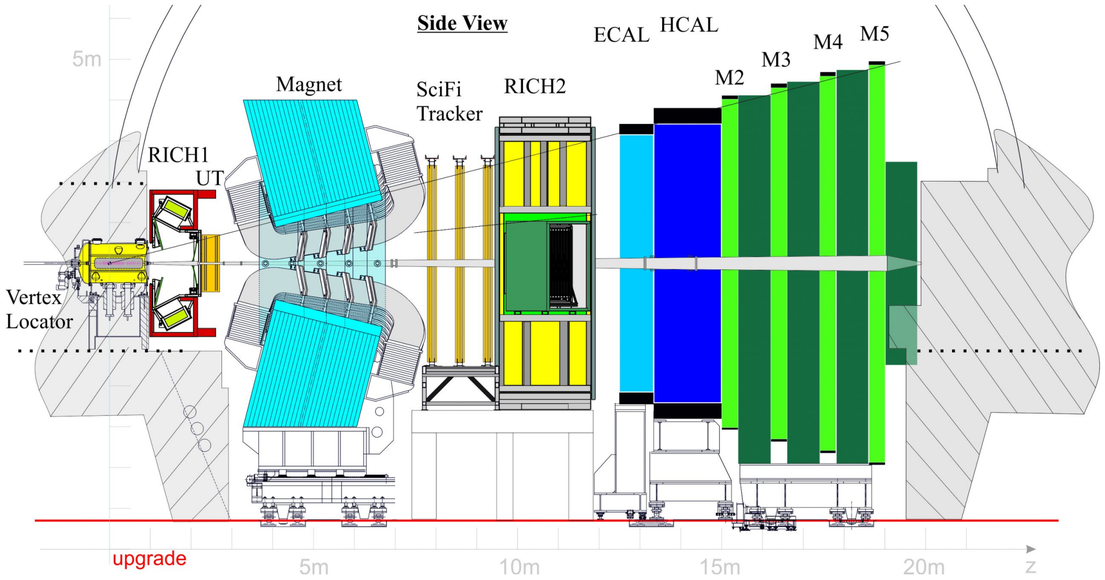
OVERVIEW UPGRADE I

- **Tracking detectors** exchanged due to radiation damage
  - Upgrade to finer granularity
    - Pixel VELO getting as close as 5mm to beam
    - New silicon based Upstream detector (UT)
    - SciFi tracker 11.000km of scintillating fibre
- New RICH mechanics, optics and photodetectors

  → better granularity
- **New electronics** for all systems

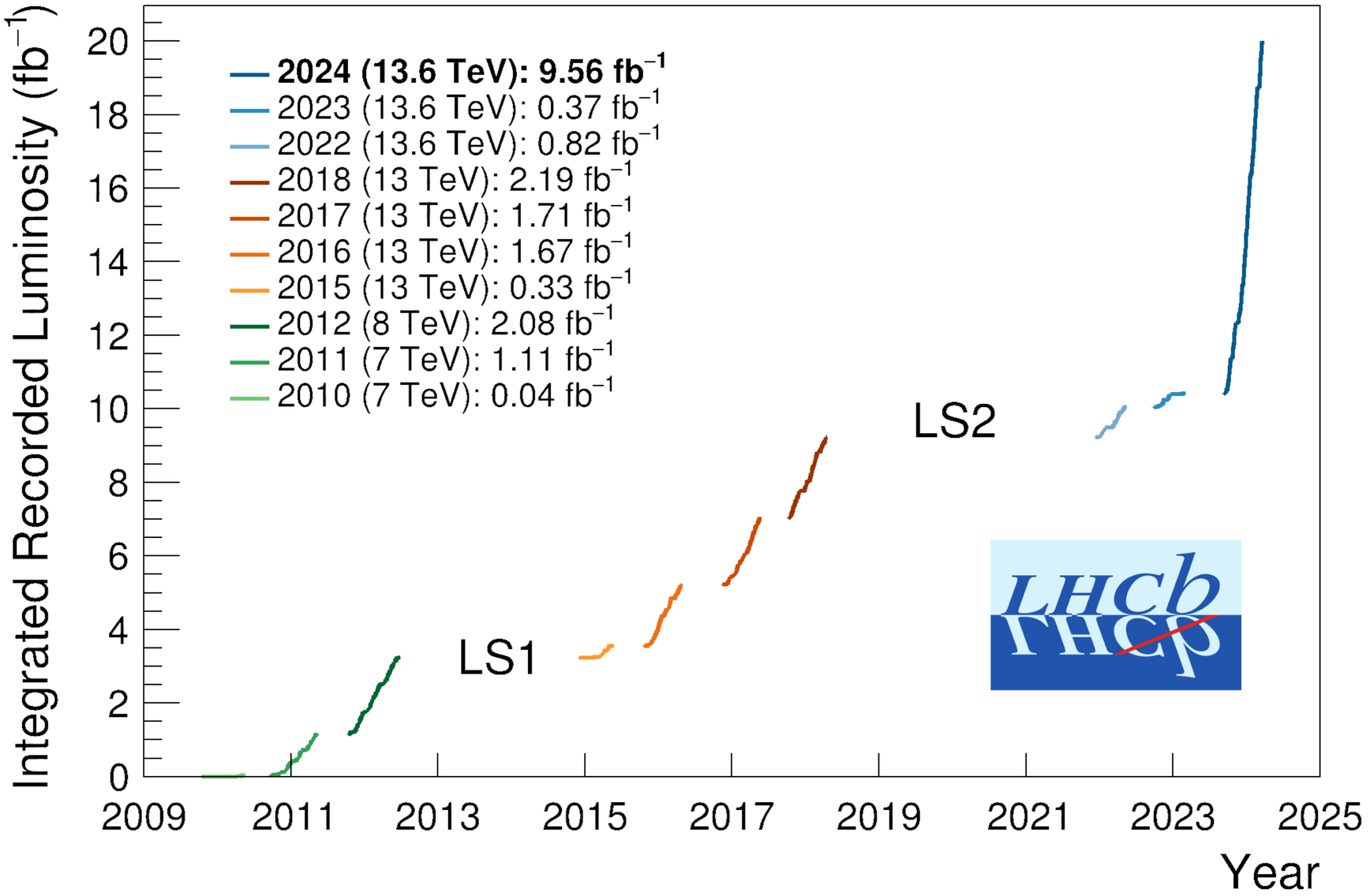
Basically brand new detector

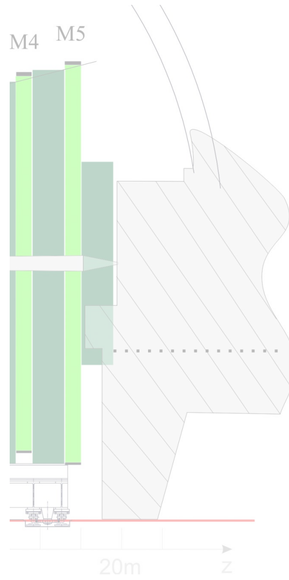




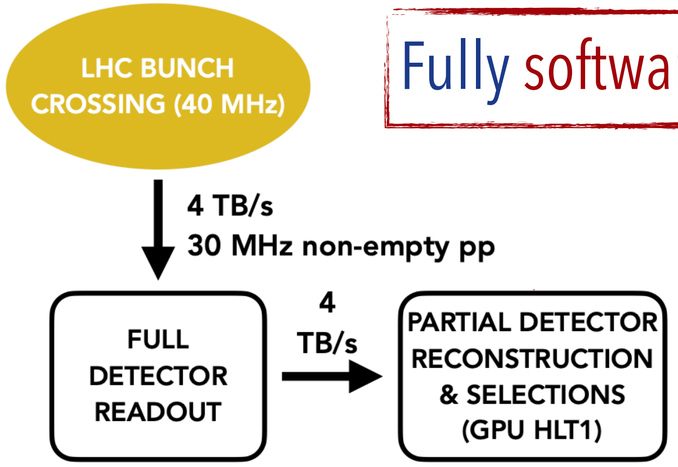
OVERVIEW UPGRADE I

- **Trackin**
  - Upgr
    - Pi
    - Ne
    - Sc
- New RIC
  - → bett
- **New el**





Collision dataflow during Run 3



Fully software trigger

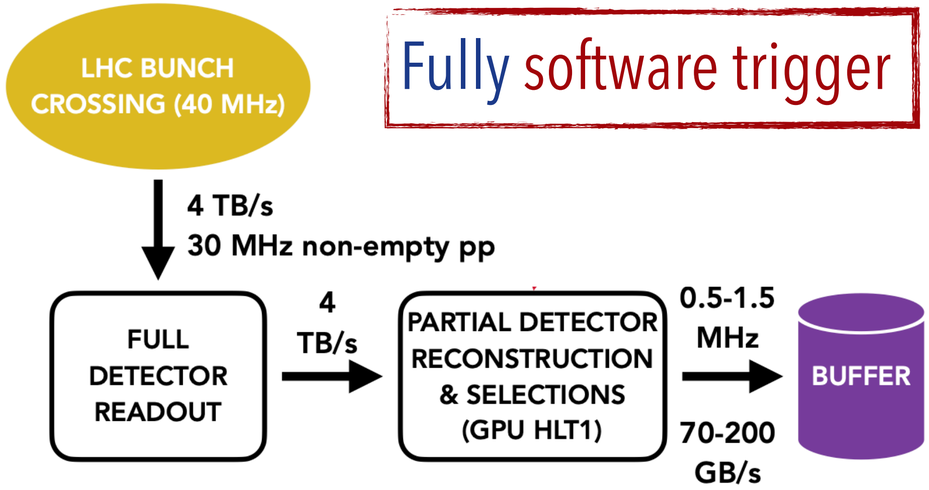
New FPGA cards (PCIe40) enable:

- Readout of subdetectors at 30MHz,
- Track reconstruction crucial to build events

  → highly **parallelizable** process

- Run HLT1 on GPUs in Allen framework

Collision dataflow during Run 3

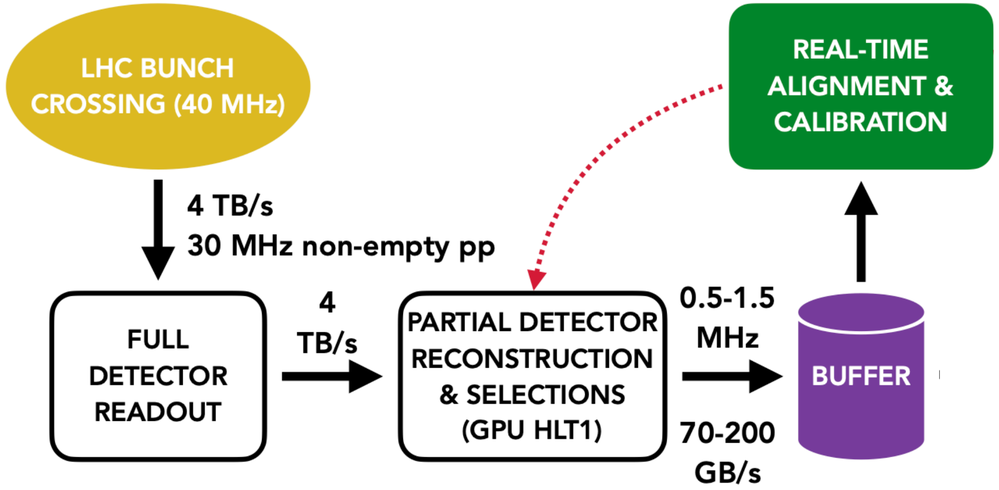


Fully software trigger

Event Builder (EB) server host HLT1:

- Add subdetector information to events and group them
- Event Filter Farm (EFF)
  - → process event packages through selection
  - → if successful give to storage
- Reduction is a factor 30

Collision dataflow during Run 3



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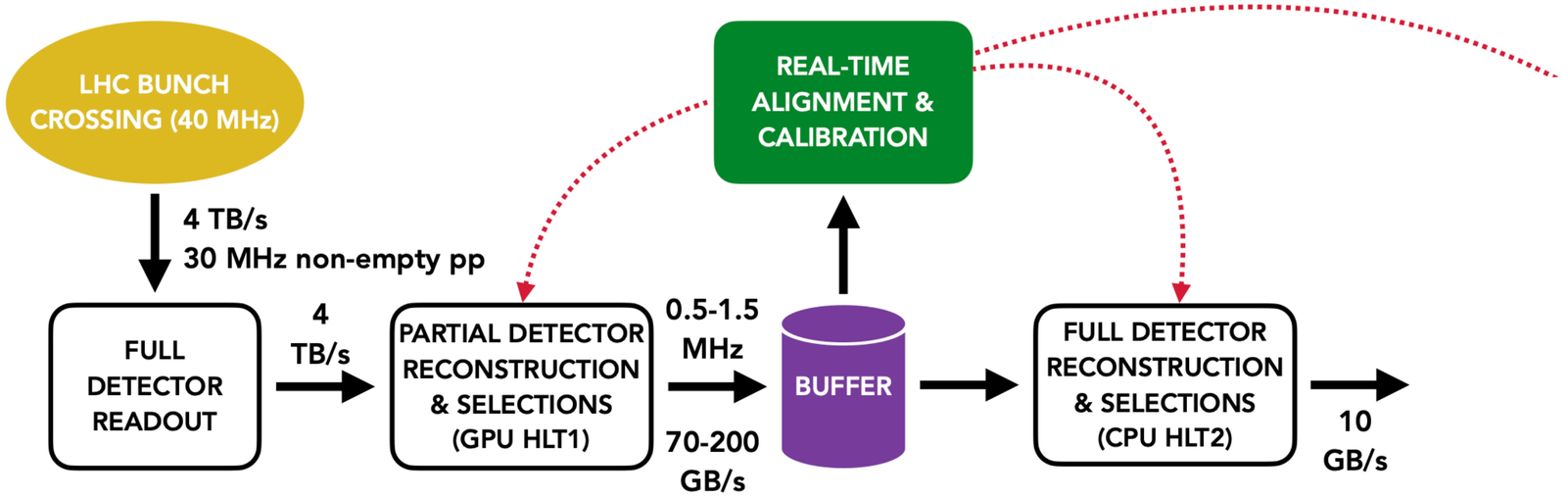
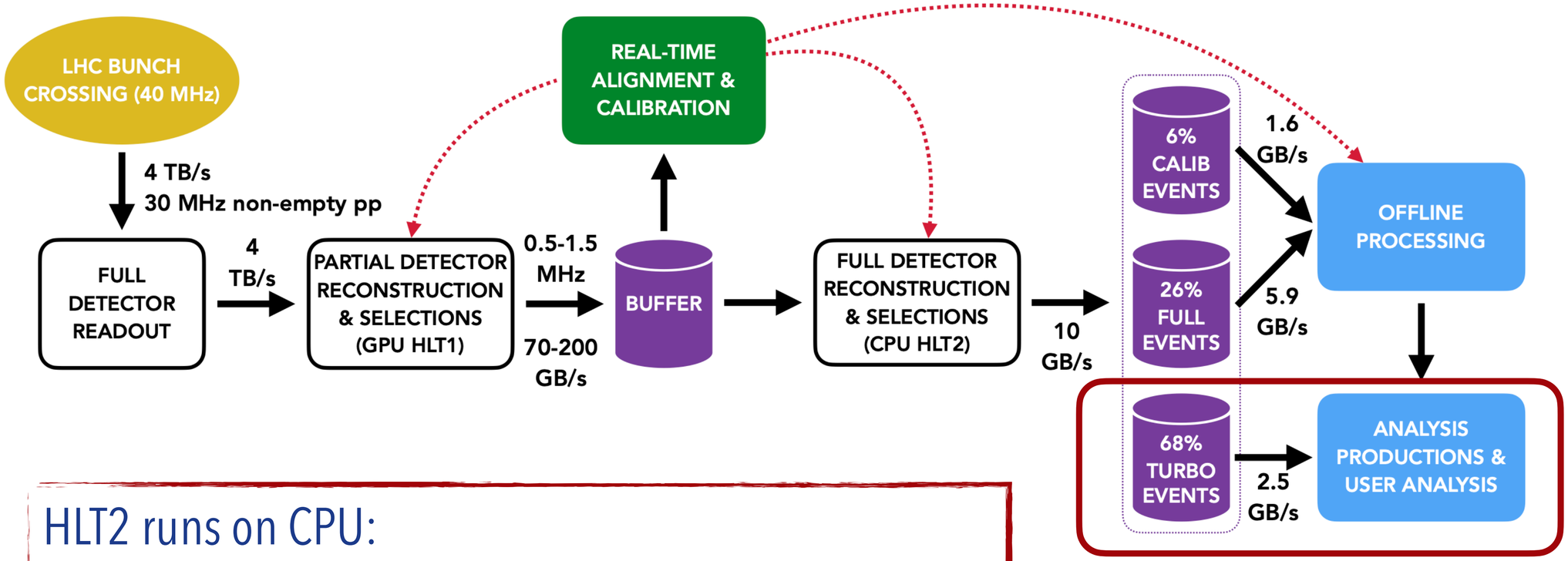


HLT2 runs on CPU:

- Generally same as in Run 1+2: full event reconstruction + selection
- However **bandwidth constraint** at 10 GB/s

  → selection for each decay optimise so all trigger lines add up

Collision dataflow during Run 3



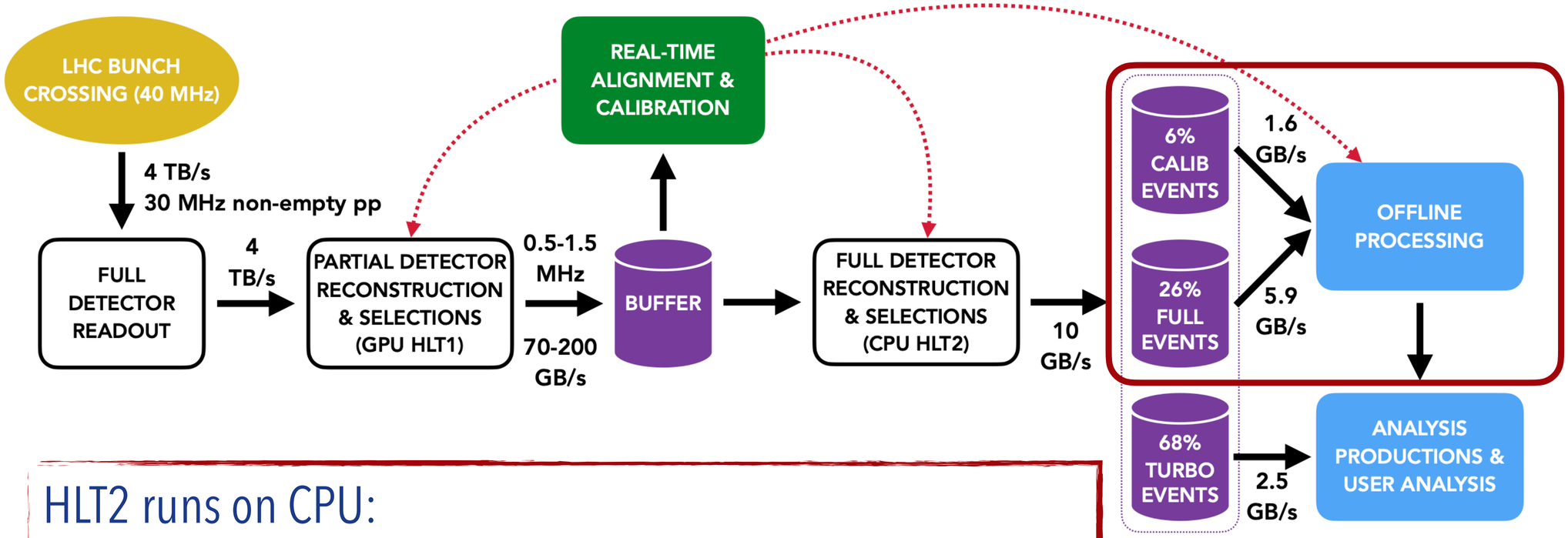
HLT2 runs on CPU:

- **Turbo** model becomes default with 2/3 of the data

  → no further offline reconstruction

  → but smaller event size, more can be stored

Collision dataflow during Run 3



HLT2 runs on CPU:

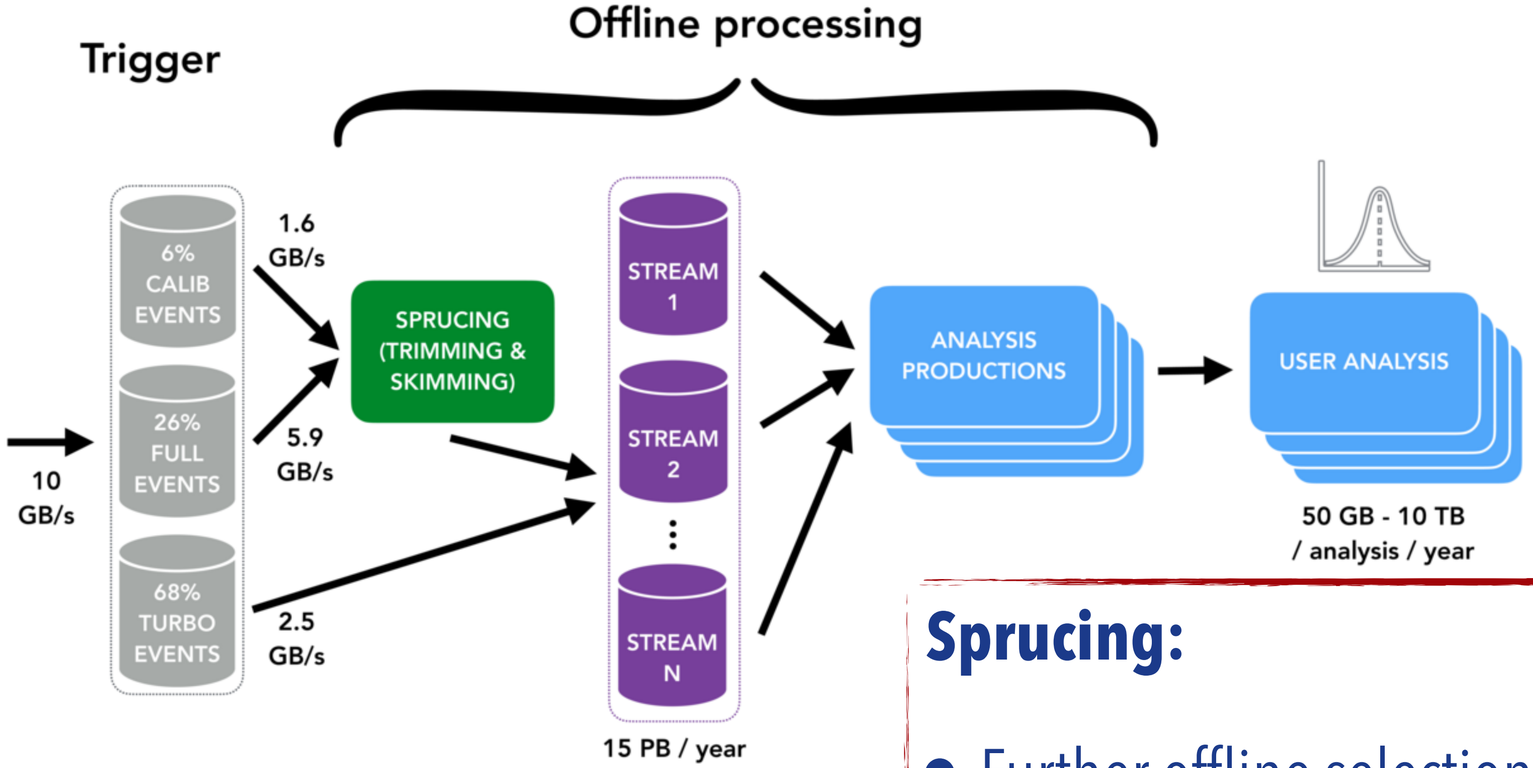
- Sometimes we need more information

  → use **persistency** model

  → either full event (*persistreco=True*)

  or defined extra information (define with *extra_outputs*)

Offline reconstruction Run 3



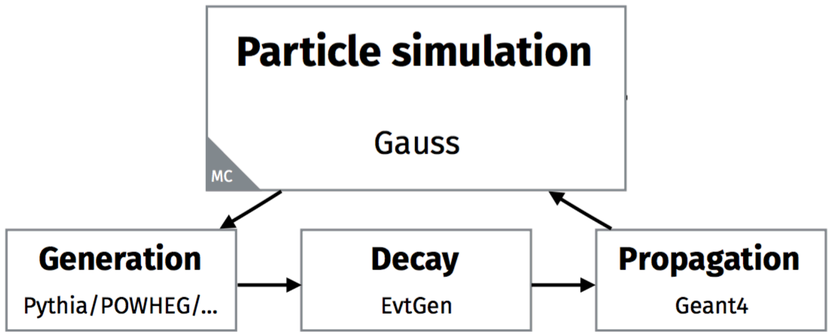
Careful DaVinci changed for Run 3 challenges → FunTuple

Sprucing:

- Further offline selection
- Turbo only passthrough, rest tighter selection (resprucing)
- HLT2 can use 10 GB/s to tape, but only 3.6 GB/s to disk
- Sprucing and HLT2 same code base → interchangeable

Simulation dataflow

But what about simulation?



Creating particle simulation:

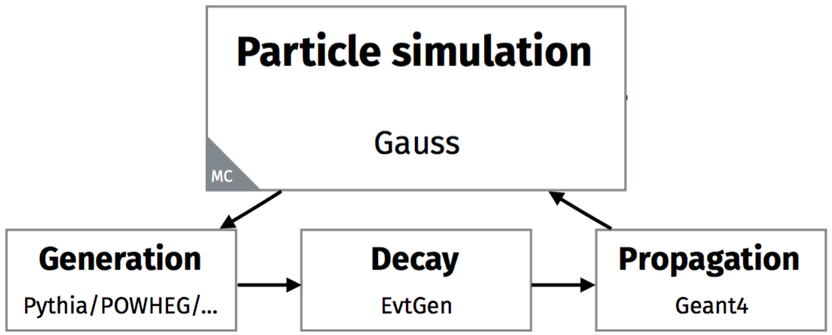
- Generation of the hard process e.g. Pythia
- Decay processed with DecFiles in EvtGen
- Propagation through detector: Geant4
- All executed in Gauss framework

Simulation dataflow

But what about simulation?

Generator level MC

→ TRUE variables



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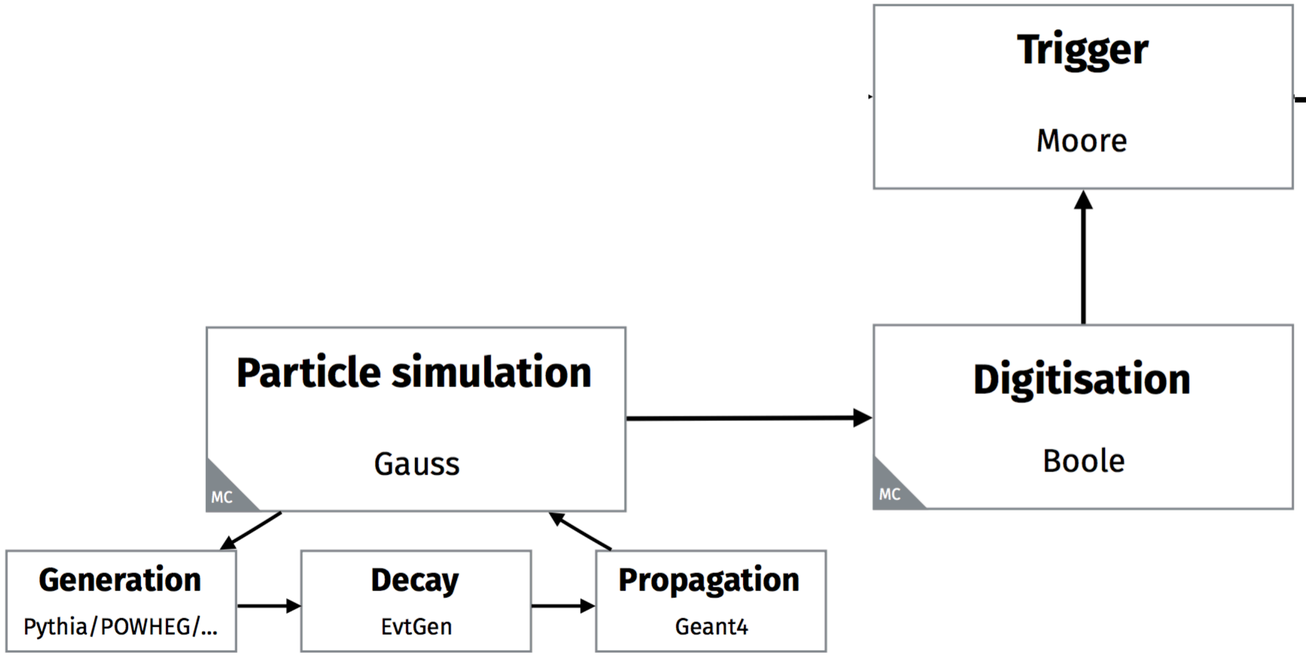
Simulation dataflow

More details on the starterkit webpage



After generating the particle simulation:

- Digitalisation of detector response with Boole
- Simulation can be processed like data
- Access to efficiencies

Simulation dataflow

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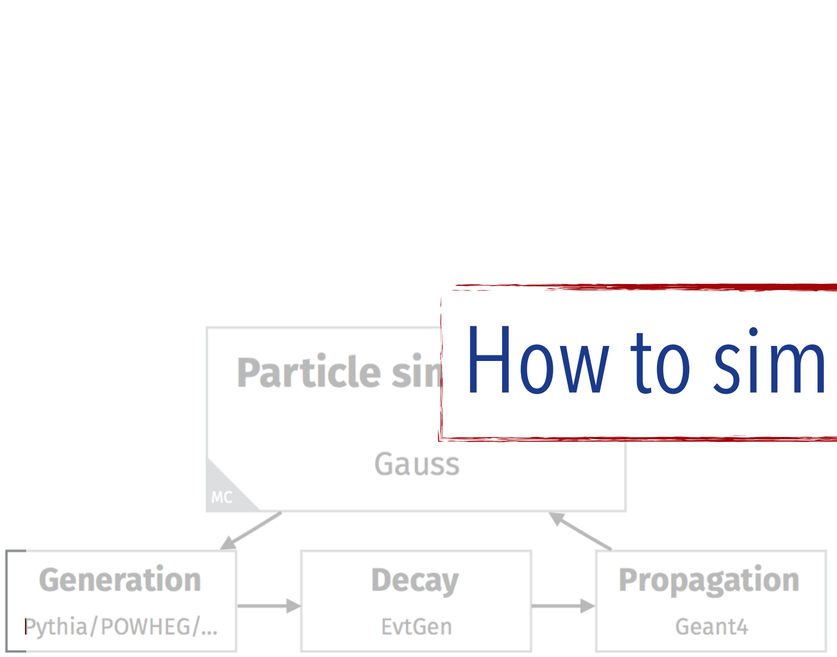

... Reconstruction level MC

How to simulation and MC request on Wednesday

After generation, the particle simulation:

Digitisation of detector response with Boole

- Simulation can be processed like data
- Access to efficiencies

Analysis flow

First accessing Ntuples

Step 1

Testing scripts

Run locally

Starterkit lesson about it

Analysis flow

First accessing Ntuples

Step 1

Testing scripts

Run locally

Starterkit lesson about it

Step 2a

Running scripts on grid

via ganga

Starterkit lesson about it

Analysis flow

First accessing Ntuples

Step 1

Run locally

Starterkit lesson about it

Step 2a

Running scripts

via ganga

Starterkit lesson about it

Can we do something more centralised to reduce human error?

Analysis flow

First accessing Ntuples

Step 1

Testing scripts

Run locally

Starterkit lesson about it

Step 2a

Running scripts on grid

via ganga

Starterkit lesson about it

Step 2b

Running scripts centralised

via Analysis Production

Starterkit lesson about it

Analysis flow

First accessing Ntuples

Step 1

Testing sc

Run locally

Starterkit lesson about it

Step 2a

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via ganga

Starterkit lesson about it

Step 2b

Running scripts

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via Analysis Production

Starterkit lesson about it

Introduction to Analysis Production on Thursday

Analysis flow

Now the actual analysis flow

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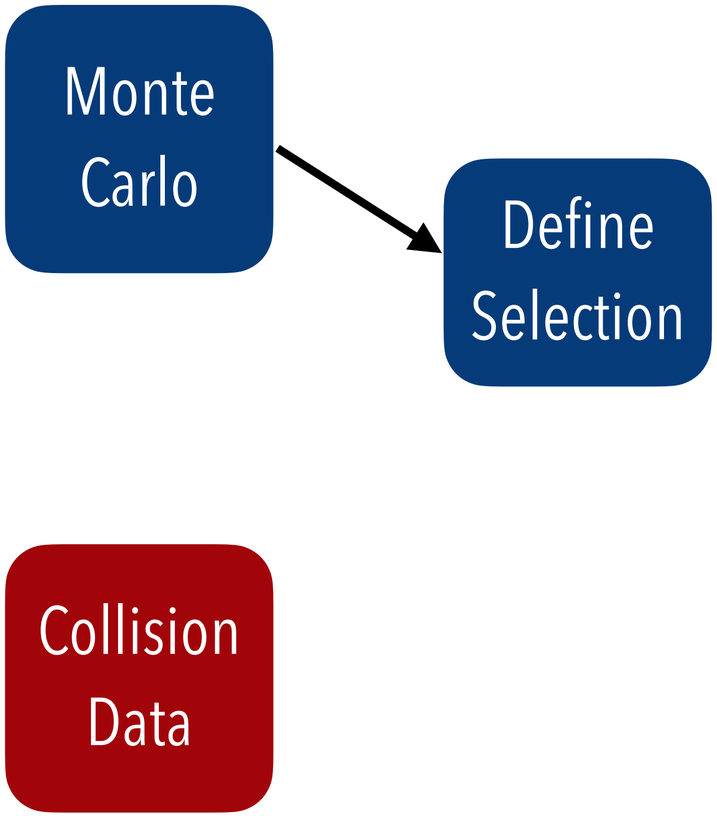

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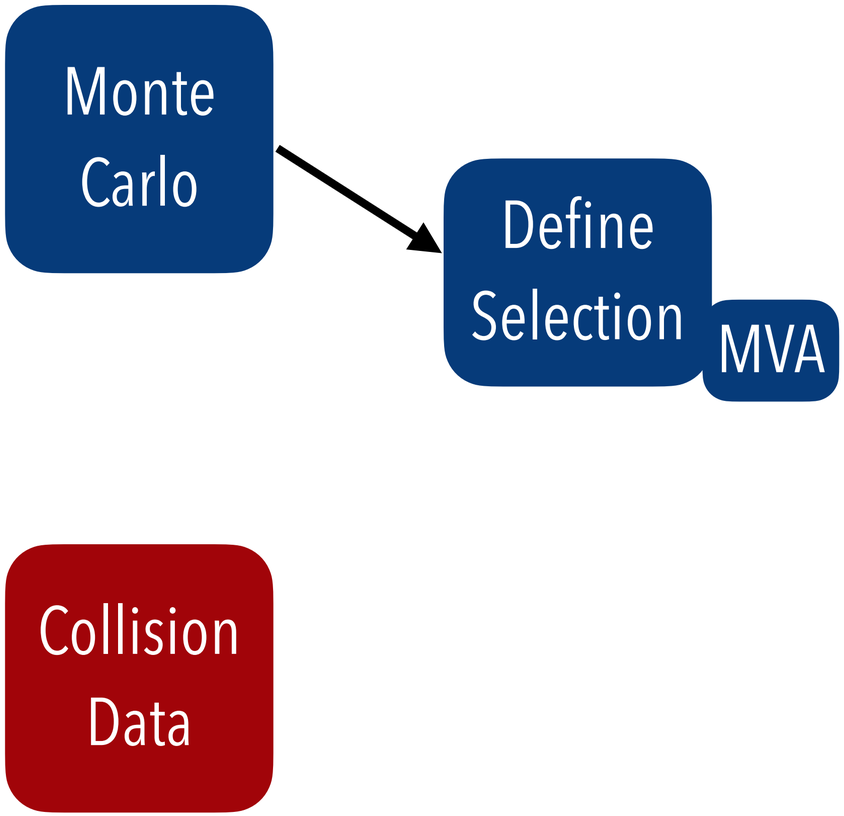
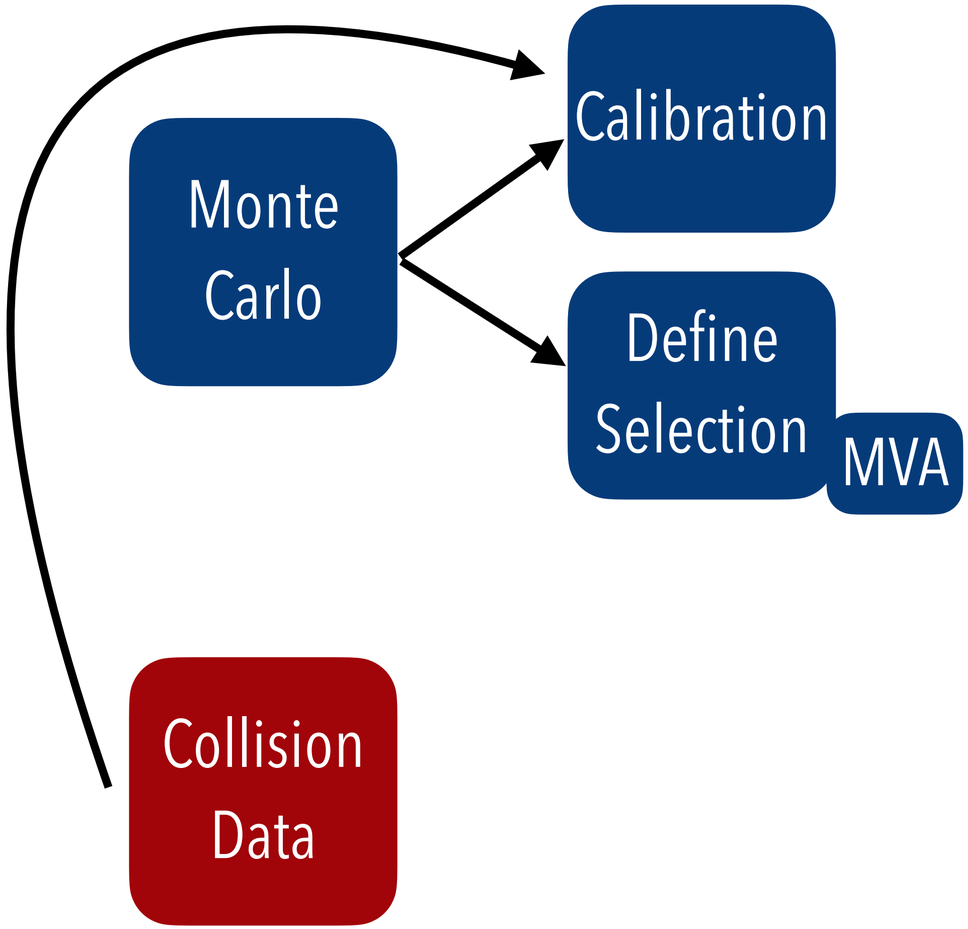


Analysis flow

LHCb software: PIDCalib, TrackCalib,…



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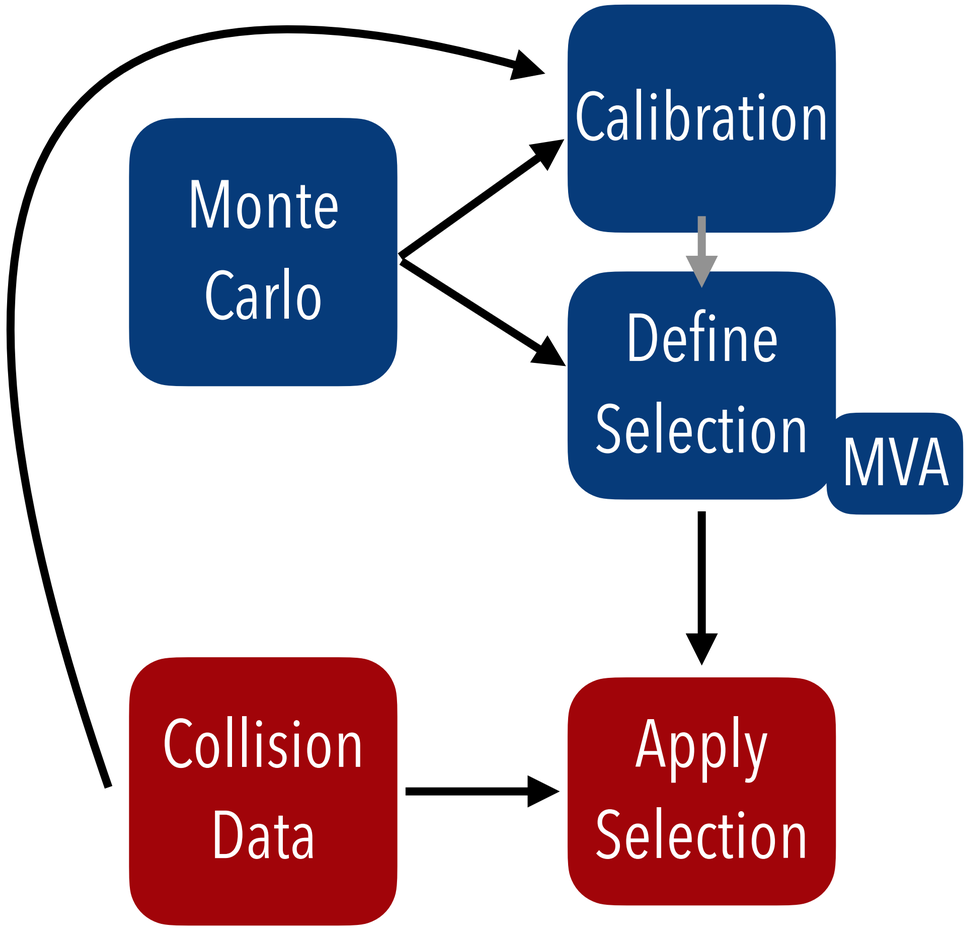

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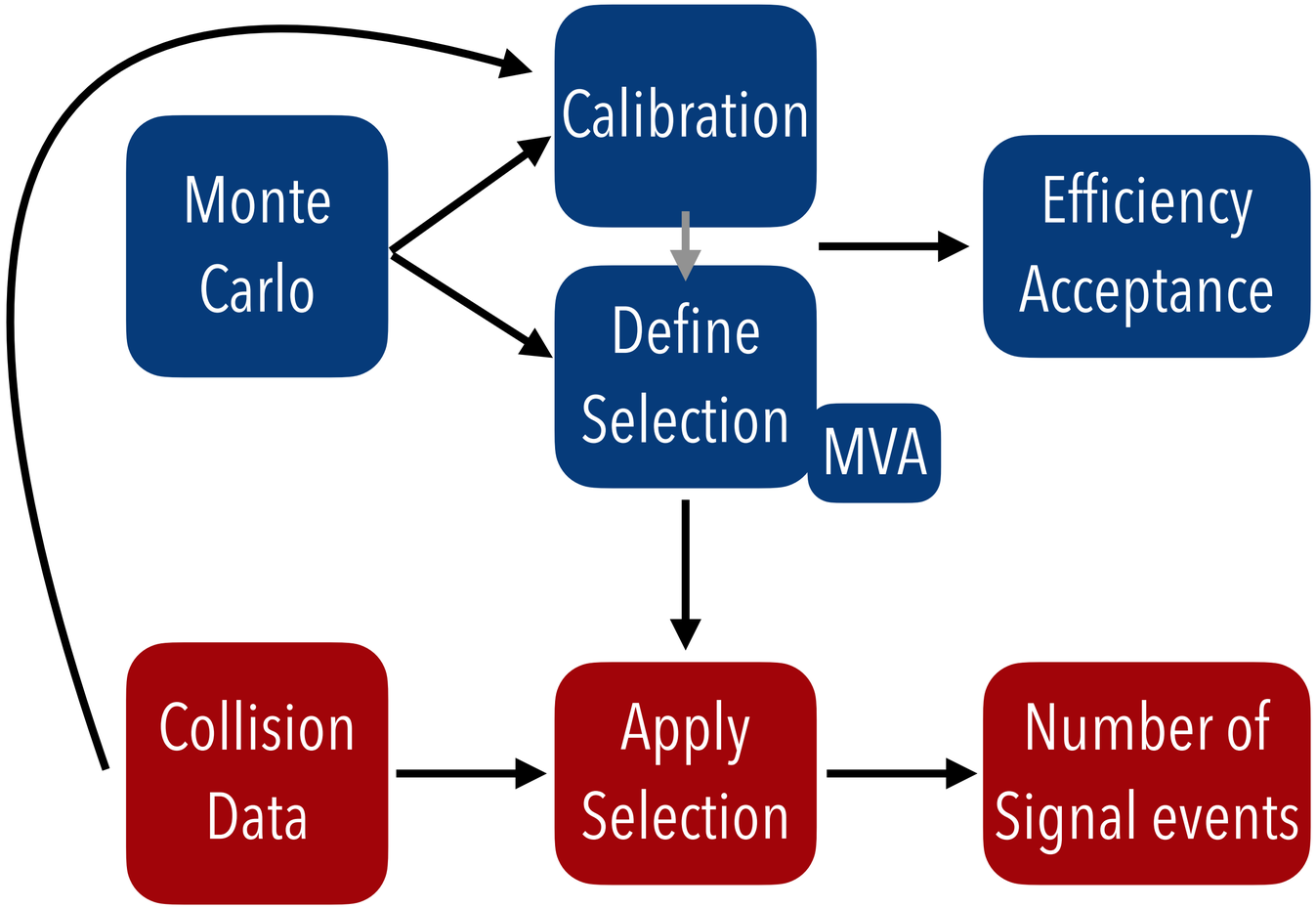

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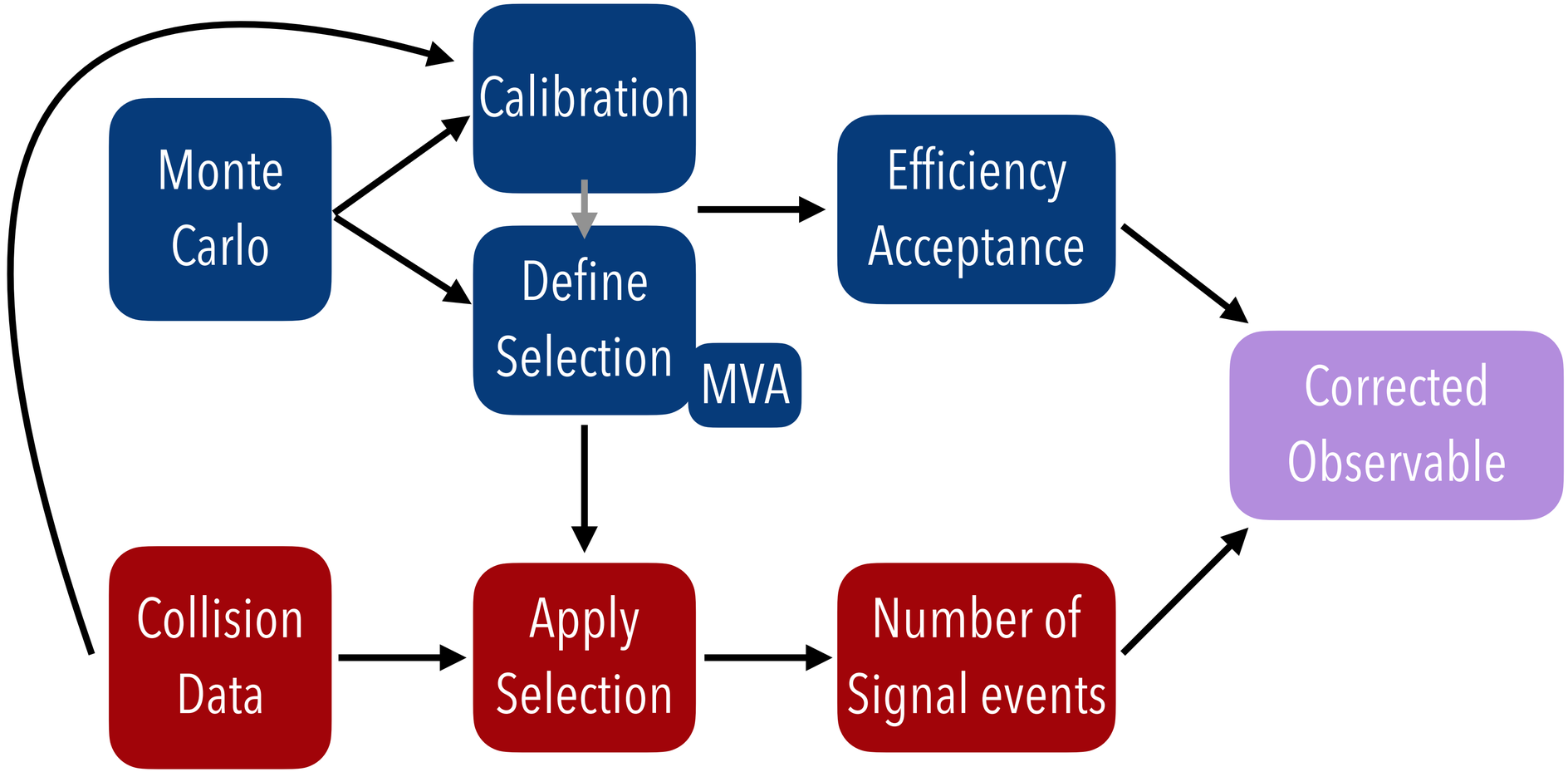

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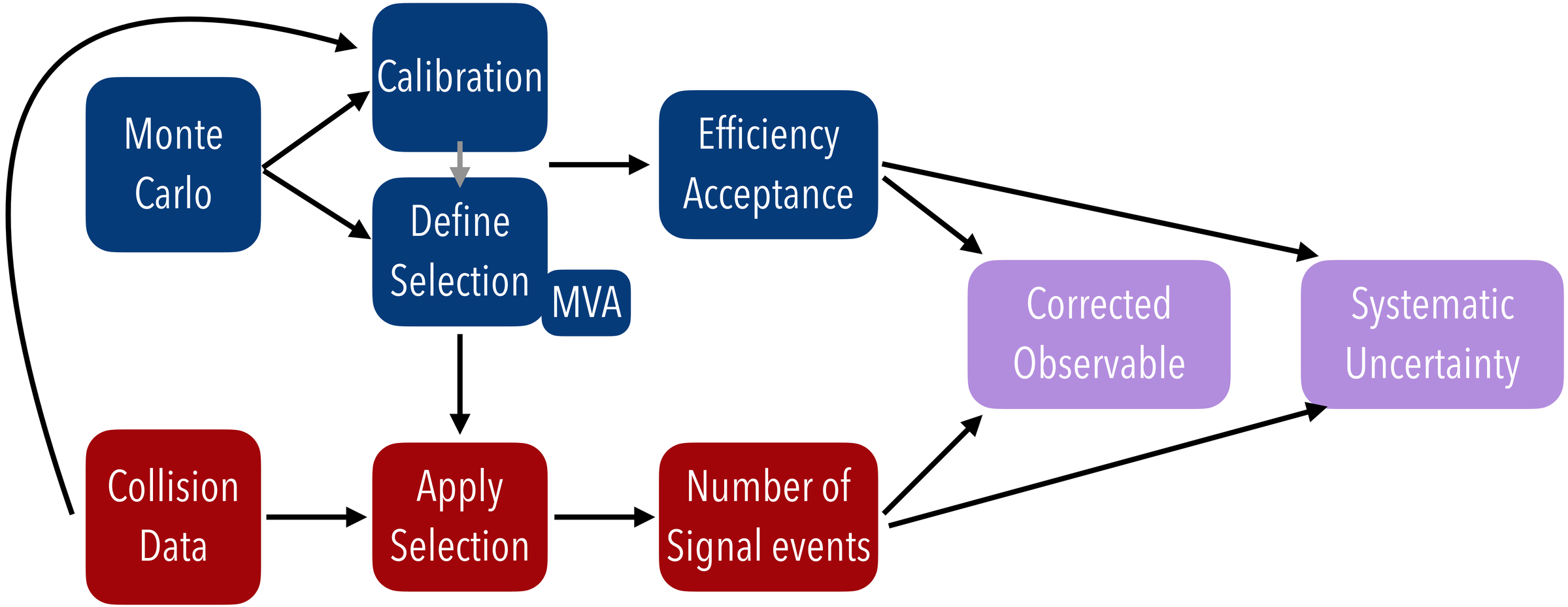

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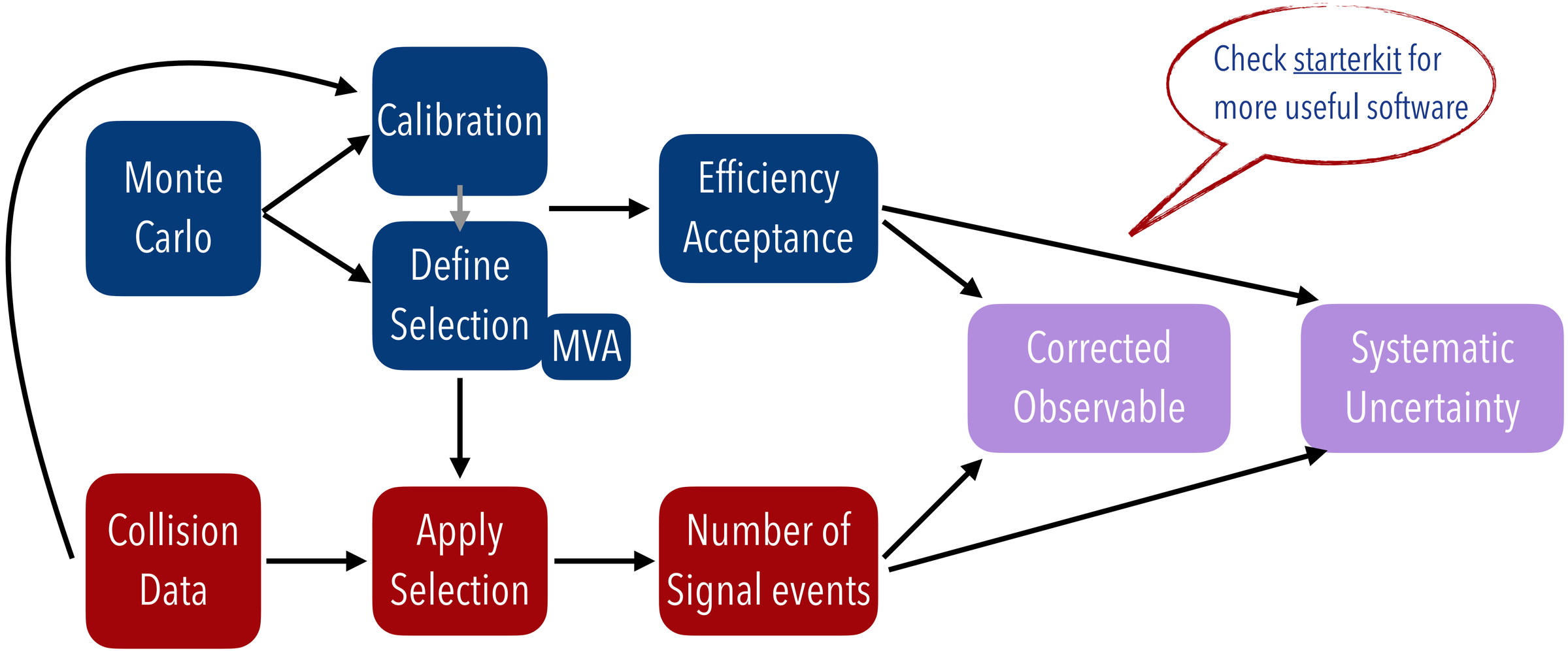

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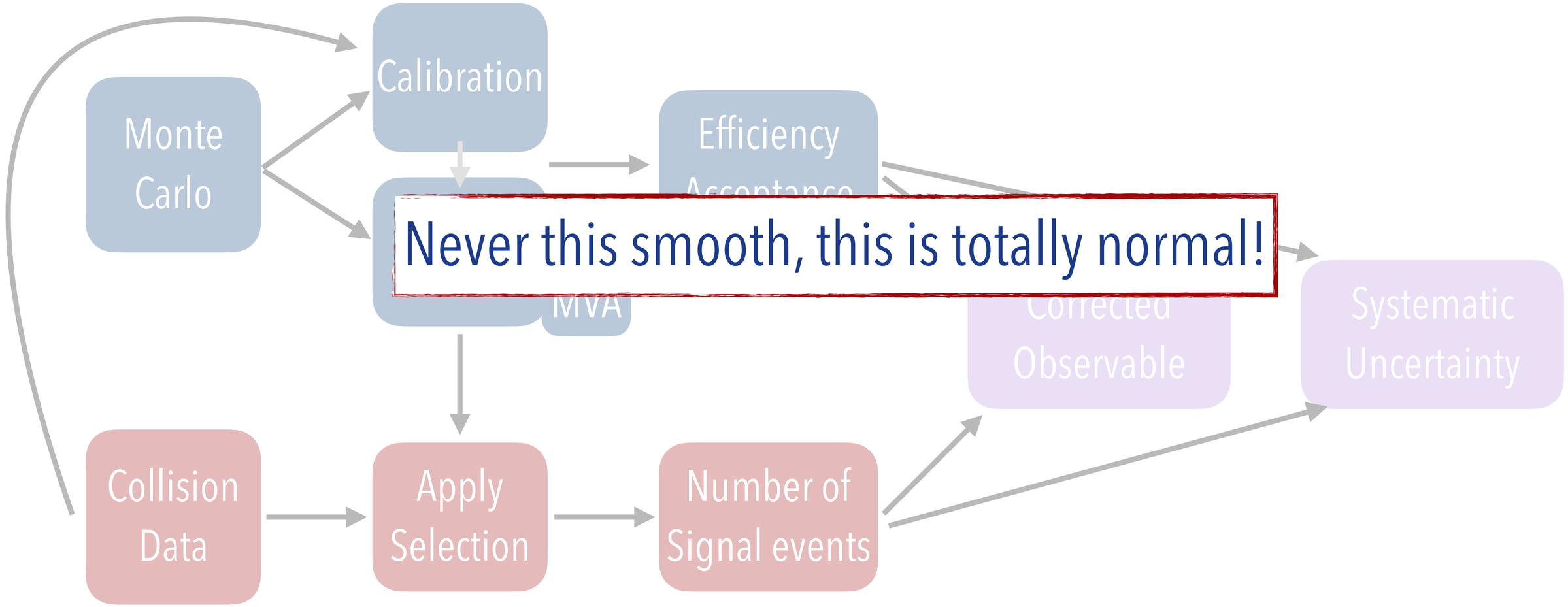

Towards publication

Analysis now in principle done:

- Analysis note: Contains all studies, documentation of your analysis, published on CDS at the end

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Helpful are the LHCb guidelines for the preservation,

the flowchart for review steps, the Publishing FAQ

And ask your colleagues.

In the end we are a collaboration! :)

Analysis preservation

Analysis preservation needs to things

- If you don't use the lb-conda environment , preserve the package versions of the software e.g. with your own conda environment or a docker container
- Analysis code need to be accessible on Gitlab, the use of snakemake can make it easier to make your workflow reproducible

Analysis preservation

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  e.g
- An er
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Never heard of snakemake?

Check session on Monday and use Friday to ask questions