B-tagging with fast tracking at the ATLAS trigger

Annual Meeting of the Swiss Physical Society

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ATLAS EXPERIMENT

UNIVERSITÉ DE GENÈVE

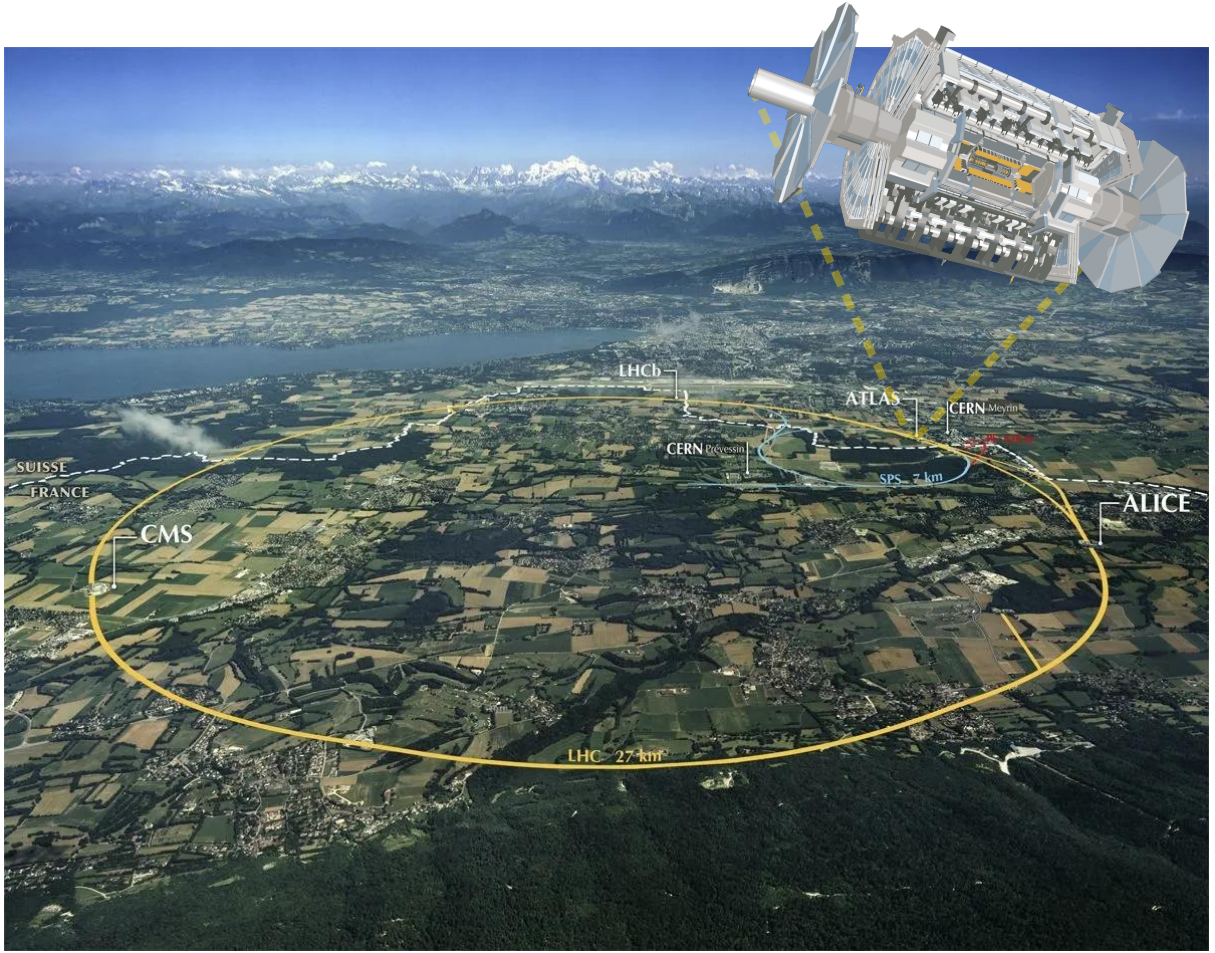
FACULTÉ DES SCIENCES

Overview

- Introduction to ATLAS trigger
  - General design
  - Main concepts behind the *High Level Trigger* (HLT)
- B-tagging at trigger level for Run3
  - Why and how we do it with *fast* tracks
  - Preliminary results

Introduction to the ATLAS trigger

- ATLAS is one of the 4 main experiments installed on the ring of the Large Hadron Collider (LHC)
- At LHC bunches of protons collide every ~ **25 ns** (40 MHz)
- From each bunch crossing we get 30-60 *p-p* interactions
- Out of these we want to study SM and look for possible *new physics!*



Introduction to the ATLAS trigger

- A **robust trigger** system is required because:

1) Technical constraints

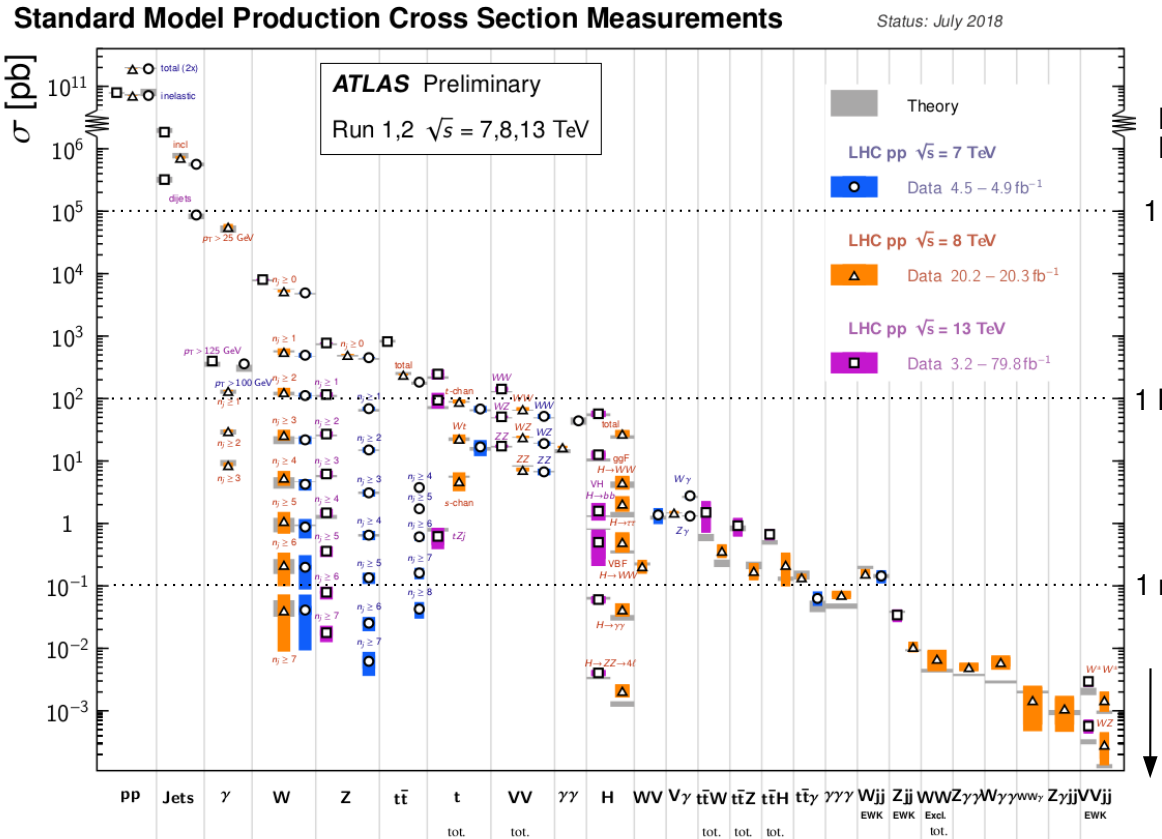
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	92 M	96.7%
SCT Silicon Strips	6.3 M	98.3%
TRT Transition Radiation Tracker	350 k	96.6%
LAr EM Calorimeter	170 k	100%
Tile Calorimeter	5200	99.2%
Hadronic End-Cap LAr Calorimeter	5600	99.9%
Forward LAr Calorimeter	3500	99.8%
LVL1 Calo Trigger	7160	99.9%
LVL1 Muon RPC Trigger	383 k	99.8%
LVL1 Muon TGC Trigger	312 k	100%
MDT Muon Drift Tubes	344 k	99.7%
MicroMegas NSW	2.1 M	98.0%
STGC NSW	358 k	99.2%
RPC Barrel Muon Chambers	383 k	87.7%
TGC End-Cap Muon Chambers	312 k	99.4%
ALFA	10 k	100%
AFP	430 k	100%
LUCID	2x16	100%
ZDC	2x20	100%

- The whole detector system has more than **100M channels**
- Reading out is expensive (~ 1 MB/evt)
- Cannot afford to write at 40MHz (more than 40 TB/s!!!)

Introduction to the ATLAS trigger

- A **robust trigger** system is required because:

2) Physics!



Rates considering average instantaneous Luminosity: $L_{inst.} \simeq 10^{34}\,cm^2\,s^{-1}$

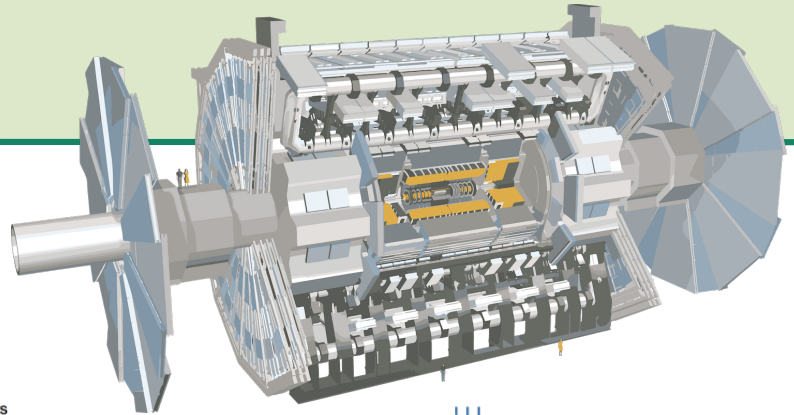
1 kHz

1 Hz

1 mHz

Possible new physics

Introduction to the ATLAS trigger

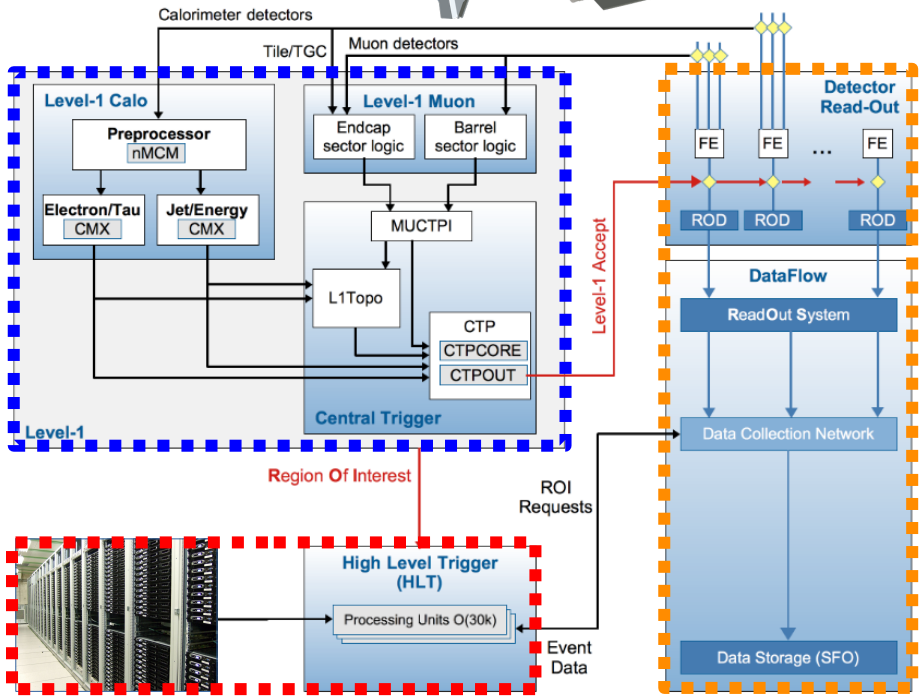


- Structure of the ATLAS trigger can be summarized as:

- **Level 1 Trigger (L1)**
  Hardware based for fast reco. from the **Calo** and **Muon** systems

- **High Level Trigger (HLT)**
  CPU farm running more sophisticated algorithms closer to offline reco.

- **Read-Out and DataFlow** infrastructure

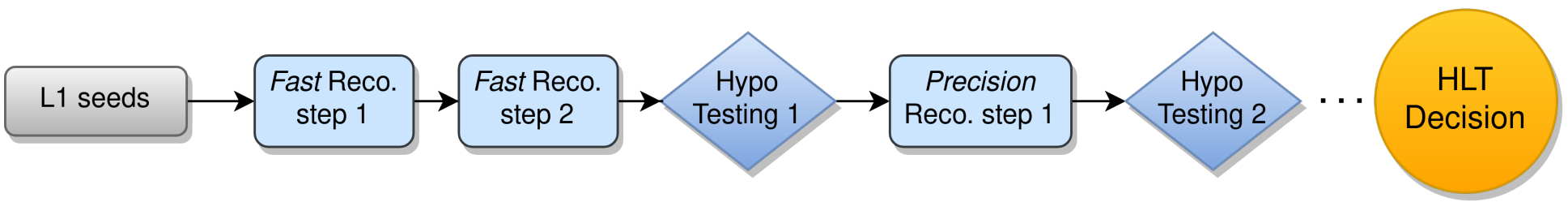


HLT main concepts

- The **ideal** goal of the HLT is to perform event selection with **offline-like** precision, within online processing constraints

- Event selection strategy proceeds in steps → **chains** of algorithms
  - *Fast* trigger specific reconstruction, typically in Regions of Interest (**RoI**) identified at L1
  - *Precision* reconstruction, as close as possible to offline
  - *Hypothesis* algorithms, apply selections on online reconstructed quantities

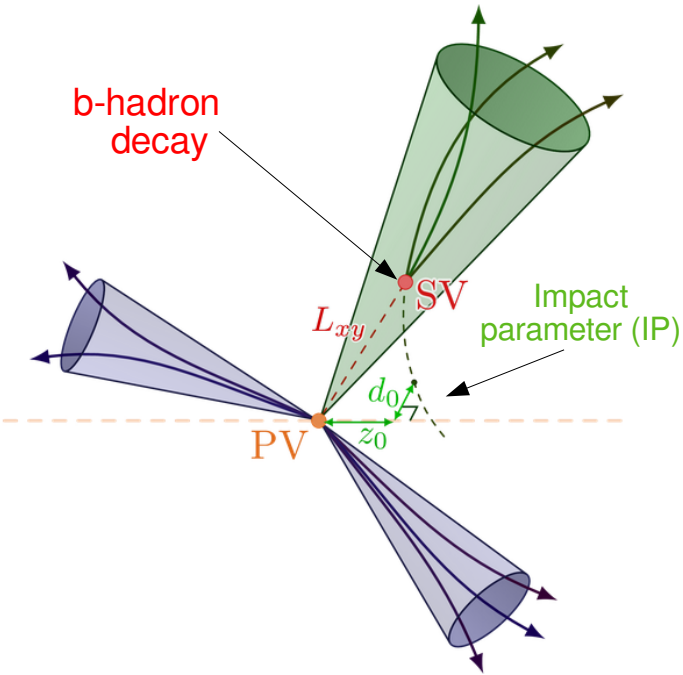
- All the different chains are gathered within a “Menu”



B-tagging

- B-tagging = identifying jets originating from b-quarks

- It exploits peculiar characteristics of b-quarks
  - Large mass (~ 4.18 GeV) and hadronisation
    → high track multiplicity
  - "Long" mean lifetime (~10^{-12} s)
    → e.g. for b-hadron of E~50 GeV: $\beta\gamma c\tau \simeq 3$ mm



- Looking for b-initiated jets is motivated by many physics cases:
  - ttbar, di-Higgs, SUSY models...

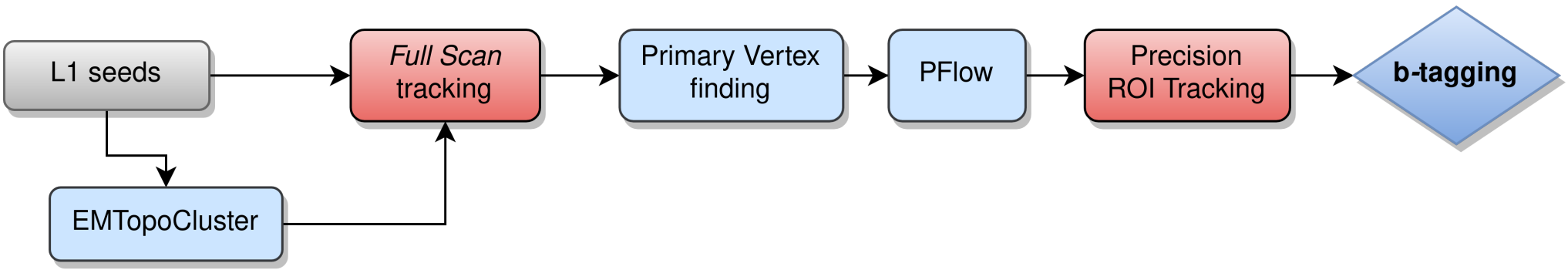
- At the HLT:
  - Run 2, b-tagging performed running MVA, using **jets**, **tracks**, **primary vertex** (PV)
  - For Run 3, heavy use of **Neural Networks**, as the DIPS architecture (more info in back-up)

B-tagging at HLT for Run 3

- To greatly increase the efficiency of b-tagging chains, full detector acceptance fast tracking (**Full Scan** tracking) is being used to build Particle Flow (PFlow) jets and PV
- Hits from the entire detector are used to reconstruct the tracks:

  ☺ More tracking information → better reconstruction

  ☹ A lot more CPU workload → Full Scan ~ **1s/evt.** Precision RoI Tracking ~ **0.35s/evt**.



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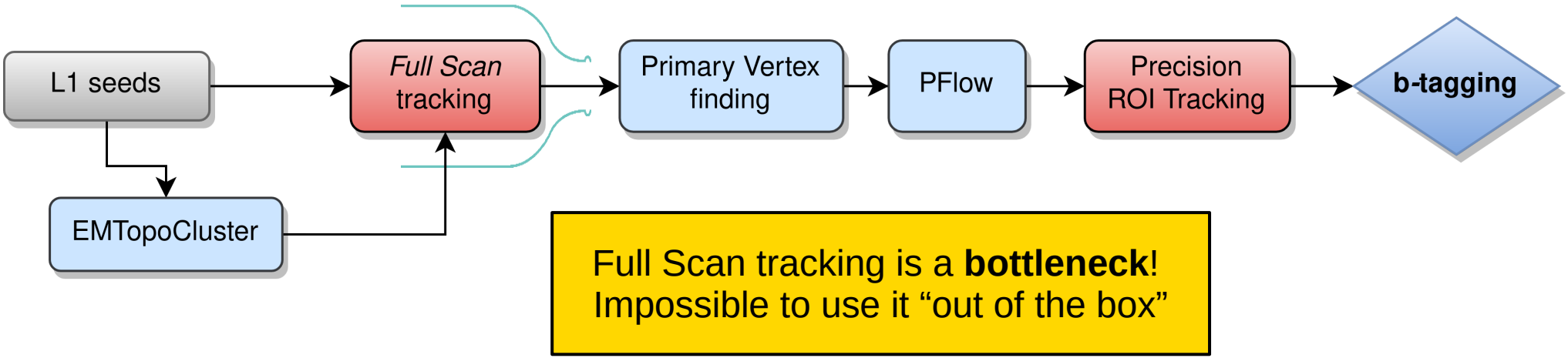
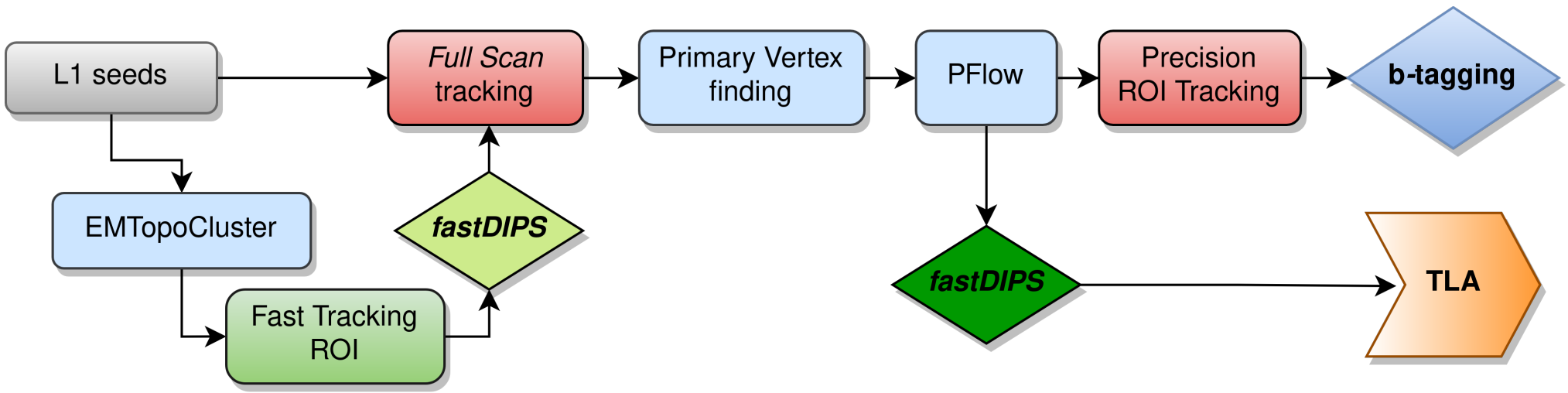


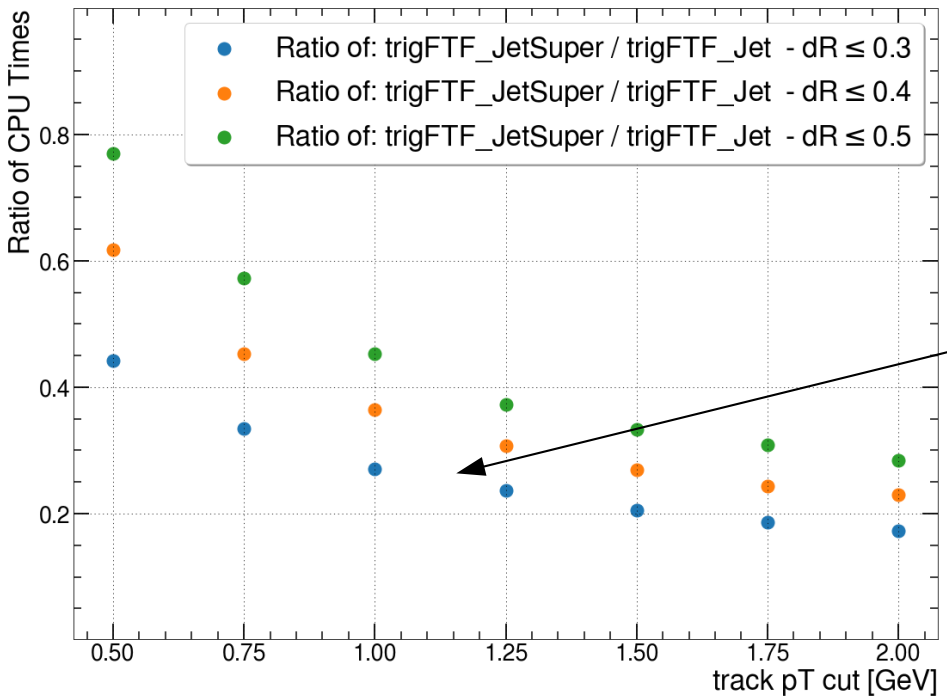
The preselection strategy

- To reduce the CPU cost and to cut down the rate before Full Scan tracking is run:
  - ➔ **Fast b-tagging** as a **preselection**
- Fast track reconstruction on a limited region of detector (Fast RoI tracking) used as input to b-tag deep learning algorithm (fastDIPS)
- A second dedicated fastDIPS training allows to use b-tagging at low p_T thresholds for Trigger Level Analysis (TLA, more info in back-up)



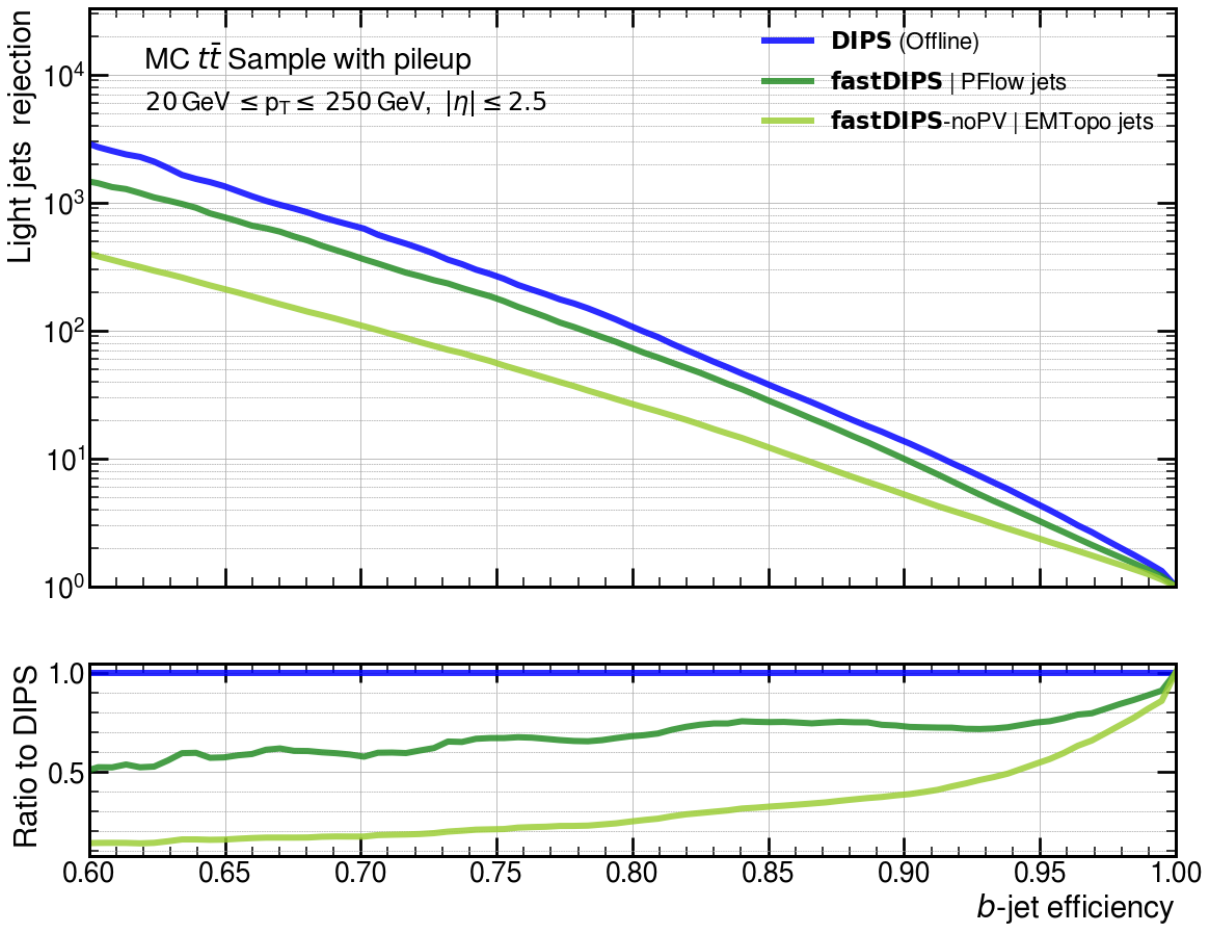
Fast b-tag CPU cost

- b-tagging step has a negligible impact
- Additional tracking step can be mitigated by tuning the two RoI key parameters:
  - Minimum track p_T and RoI size (dR)



With dR ≤ 3 and and p_T selections above 1 GeV, tracking CPU time can be reduced by factor ~4-5 w.r.t. standard tracking

Fast b-tag performances

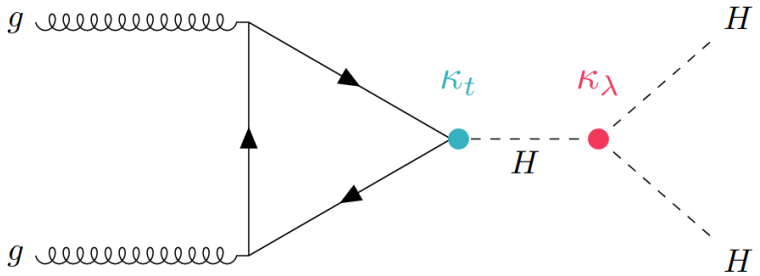


- To do b-tagging as early as possible, no PV reconstruction is done
  → **impact parameter** is computed w.r.t. to the **beam-spot** (**fastDIPS-noPV**)

- **fastDIPS** on PFlow jets does almost as well as (50-70%) offline **DIPS**
  → powerful handle for TLA

Testing the preselection

- Use case example: **HH → 4b**



- Current trigger strategy:
  - Require at least three L1 jets
  - Run HLT b-tagging chain and require at least 2 b-jets + asymmetric p_T cuts

	L1 Rate	Presel Rate	$\epsilon_{HH\to4b}$
L1 + HLT (HH→4b)	**7600 Hz**	**-**	**0.59**

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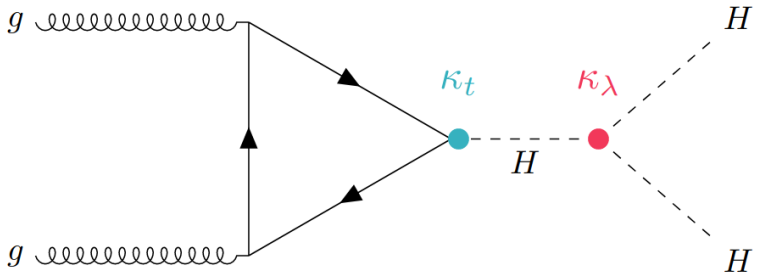

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Not affordable!!!
Full Scan tracking can run at **8 kHz** shared between **all** chains

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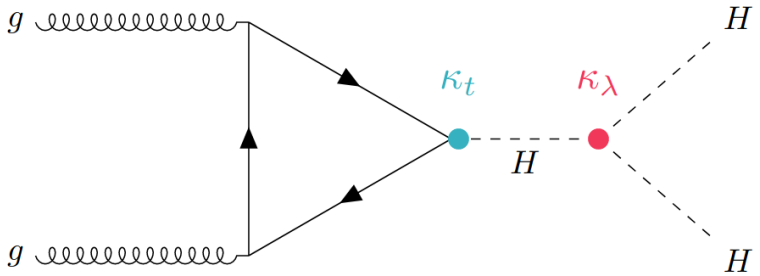

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	L1 Rate	Presel Rate	$\epsilon_{HH\to4b}$
L1 + HLT (HH→4b)	**7600 Hz**	**-**	**0.59**
L1 + B-tag presel (85%) + HLT (HH→4b)	**7600 Hz**	**1577 Hz**	**0.58**

→ Important **rate reduction** and very **good conditional efficiency**!

Conclusions

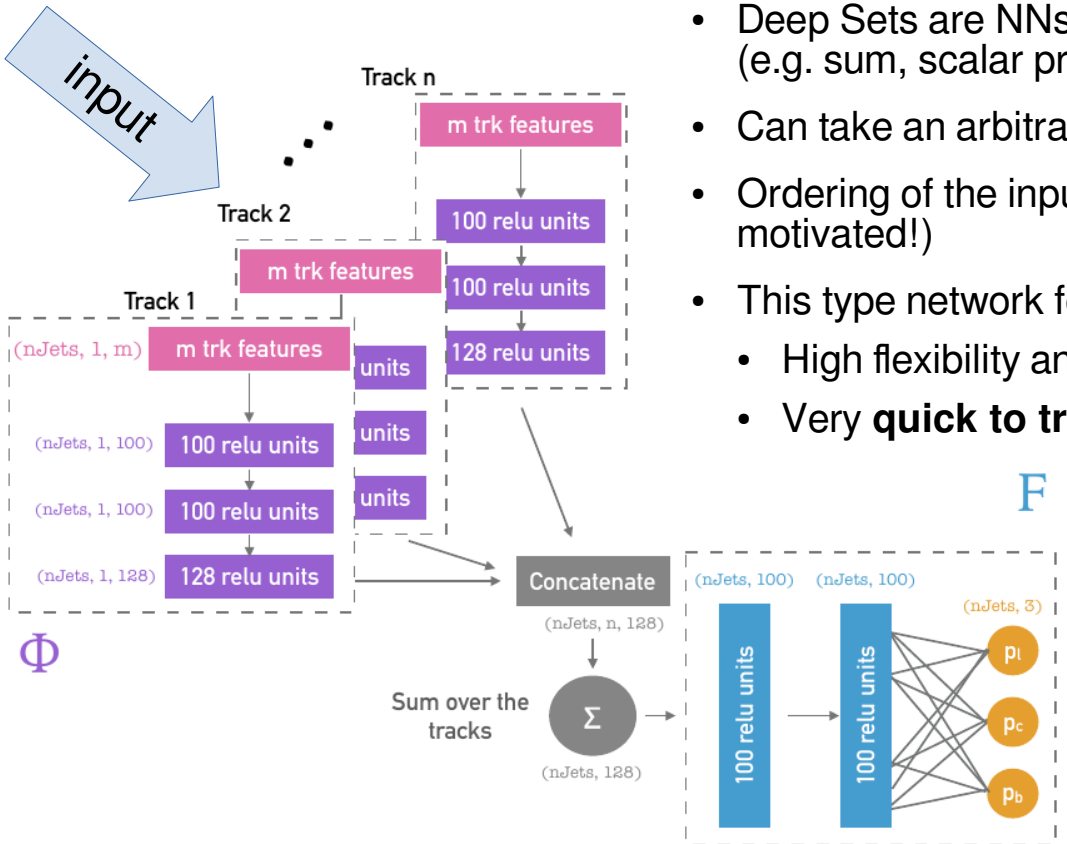
- At trigger level, **coarser** quality **tracks** can provide **relevant inputs** for a preselection specialised on b-tagging.

- The *fastDIPS* based hypo step can significantly cut down the rate at which full b-tag chains are processed, **retaining** most of the **signal** and leading to considerable **CPU savings**.

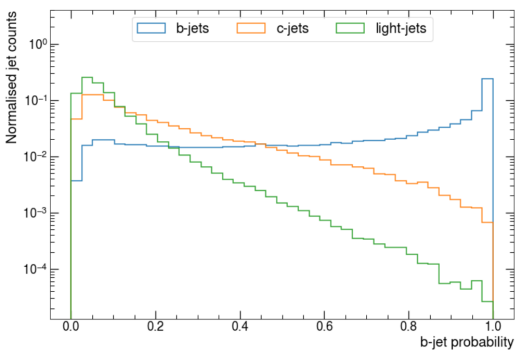
- The networks have been migrated into the HLT software and the infrastructure to run the preselection is ready for data taking, looking forward to early Run 3 commissioning data!

back-up material

DIPS in a nutshell

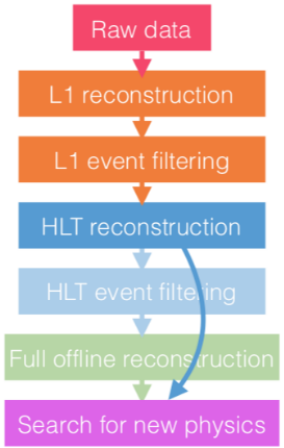


- **DIPS** = **D**eep **I**mpact **P**arameter **S**ets (paper)
- Deep Sets are NNs that can learn **permutation invariant functions** (e.g. sum, scalar product etc.)
- Can take an arbitrary number of input sets (tracks)
- Ordering of the inputs does not change the result (physically motivated!)
- This type network features also important advantages:
  - High flexibility and easy *parallelization*
  - Very **quick to train** and very **fast inference**



Trigger Level Analysis

- Search for **two-body resonances** has been a key strategy in HEP
- In ATLAS, one of the most interesting regions for this type of searches, the **EW-TeV** scale, is **trigger limited**!
  - ➔ For Run 2, HLT single jet trigger thresholds (440 GeV) constrained the $m_{jj} \gtrsim 1.5$ TeV
- Trigger level analysis (TLA) → work around the trigger limitations



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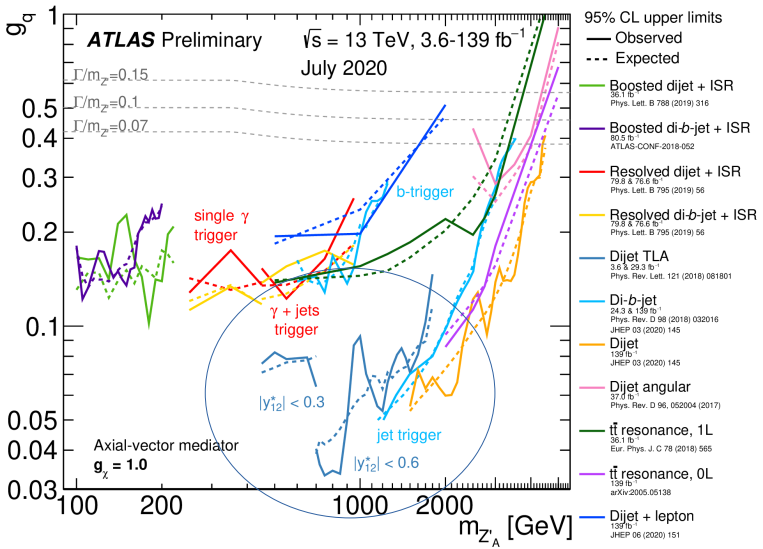

- TLA is recording **only HLT objects** relative to a given L1item, throwing away all the other information (e.g. tracking)
  - ➔ Size of the events extremely reduced (~**5 kB**/evt)
- This approach can afford much lower p_T thresholds
- Analysis on partial Run 2, using low p_T L1 triggers (75 and 100 GeV) reached much smaller coupling constant strengths w.r.t. other triggering strategies

Testing the preselection – full table

Trigger Chain	L1 Rate	Presel Rate	HLT Rate	$\epsilon_{HH\to4b}$	$\epsilon_{no\text{-}presel}$
L1 + HLT (HH→4b)	7600 Hz	-	177 Hz	0.59	-
L1 + B-tag presel (85%) + HLT (HH→4b)	7600 Hz	1577 Hz	156 Hz	0.58	0.98
L1 + B-tag presel (80%) + HLT (HH→4b)	7600 Hz	752 Hz	<150 Hz	0.57	0.96

L1 = J45p0ETA21_3J15p0ETA25 **HLT (HH→4b)** = asymm. 4j + 2b (DL1d) @ 77% eff

B-tag presel (85%) = 4j (pT > 20 GeV) + 2b (fastDIPS) @ 85% eff

B-tag presel (80%) = 4j (pT > 20 GeV) + 2b (fastDIPS) @ 80% eff

credits: Shota Hayashida