1st Year of the

NextGen Triggers Project: WorkPackage 2.7

—

"Enhanced Reconstruction for Higher Level Event Filtering"

NextGen Triggers First Technical Workshop 2024

Tuesday 26. November 2024

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WP 2.7 – Our Team

Our (2024) team is finally complete! May we introduce to you …

Lot of preparatory work before getting here.
Thanks to all the people involved!

Anna Sfyrla

Task leader

Giovanni Rupnik Boero

Ph.D. student

Thomas Matthew Critchley

Ph.D. student

6 7 11

2025

Welcome to Arantxa!

Maximilian Emanuel Goblirsch-Kolb

Task leader

Christof Sauer

Postdoc

Arantxa Ruiz Martinez

Task leader

Taking over from Anna in 2025!

WP 2.7 – Introduction and Motivation

The HL-LHC will be the last hadron collider at comparable energies for decades; **make the most of it**: *What we don't record is lost forever*

WP 2 – In a Nutshell

Enhance TDAQ for the HL-LHC using ML-based event selections, advanced acceleration technologies, enabling richer data collection and more sensitivity to new physics

WP 2.7 …

Overall optimization of the Run-4 trigger menu with focus on **physics application**

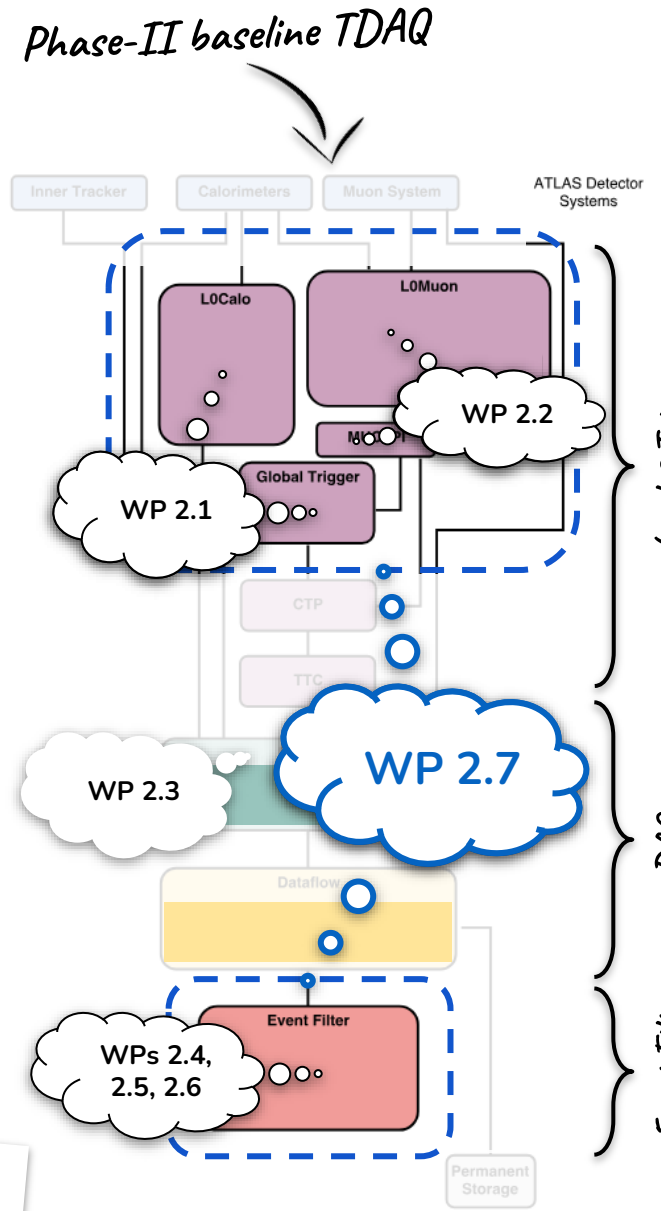
→ Exploit capabilities developed in other WP
→ Connect reconstruction and physics analyses
→ Go beyond conventional trigger strategies

Essential:
Close collaboration with other NextGen WP

Exploit new reconstruction techniques from WP2 for **enhanced particle identification**

Develop trigger concepts for **exotic, non-standard** signatures

Investigate TLA and other **real-time analysis** methods



Timeline and Milestones

– Four more years of exciting Research & Development ahead of us!

Identify **use-cases for enhanced EF reconstruction** by assessing current and **new physics scenarios**

Implement **prototype trigger signatures** with offline-like reconstruction, **refine physics performance estimates**, **optimize algorithms for sensitivity**, and evaluate dynamic tuning

Finalize and **deploy trigger signatures**, optimize dynamic **menu and algorithm features**, and **fine-tune** computational performance

Here

LS3

Start of HL-LHC

2024 | 2025 | 2026 | 2027 | 2028

Characterize potential gains to **select key signatures** for implementation, **emulate ideal trigger performance**, and establish a **dynamic bandwidth allocation** framework

Fully **implement trigger signatures** with enhanced EF reconstruction, **utilize developments from other tasks**, and assess dynamic tuning support for existing triggers

First year priorities:

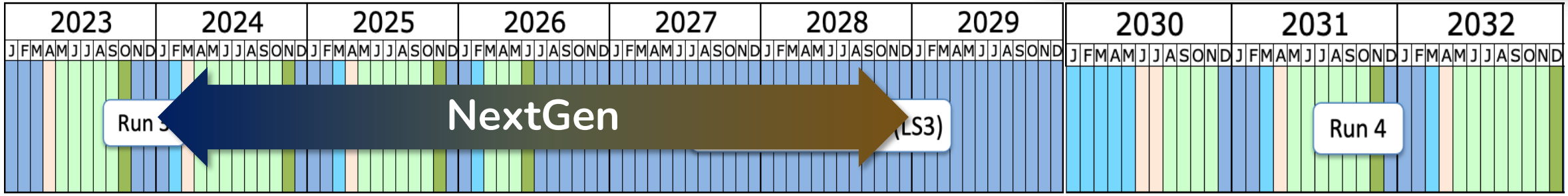
– Hiring personnel

– Start building analysis tools

– Establish synergies within ATLAS/NGT

– Identify interesting signatures/processes

Current LHC timeline



Identifying Interesting Physics Scenarios

Leaving no stone unturned:
Baseline processes for our studies


Run-4 Trigger Wishlist

ATLAS EXPERIMENT

NexTGen Next Generation Triggers

TDAQ Phase II Performance, Physics, Event Selection

CERN

As we prepare for the upcoming Run-4 of the ATLAS experiment, the NextGen Trigger (NGT) project and PPES seek your valuable insights and expertise to help shape the design of the Run-4 trigger menu, going beyond the existing Run-3 baseline.

We invite you to contribute recommendations on analyses, final state signatures, and physics processes that could benefit from enhanced trigger configurations. Our focus is particularly on analyses or signatures where the current trigger system limits sensitivity, and on exploring innovative triggers that can capture uncommon final state signatures, such as displaced vertices in long-lived particle (LLP) searches. These novel triggers aim to extend our reach to phenomena that are hardly or not at all accessible through the current selections with the existing Level-1 (L1) and High-Level Trigger (HLT) selections.

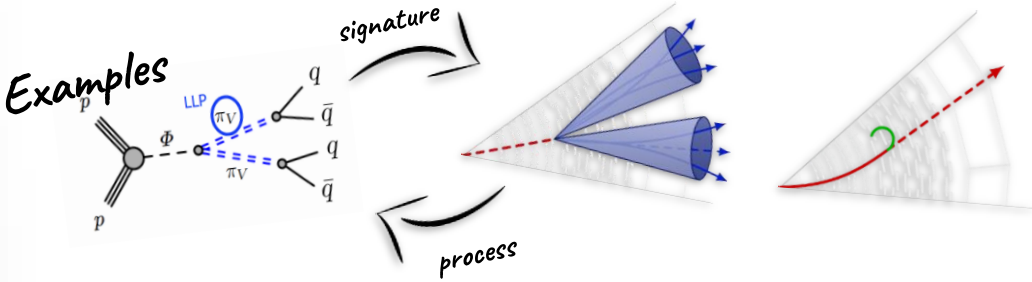
Thanks to everyone who participated and helped distribute!

Second main pillar within NextGen:

Opportunity for **close collaboration** with **WP 1.6**
- 2024: initial meetings & discussions, more in 2025!

Look in **two directions**: From **physics to signatures** as well as from **signatures to physics applications**

Examples



Collected existing experience in the collaboration through a **survey**
- embedded in ATLAS TDAQ PPES* group

→ feedback from analysis teams concerning **trigger limitations**

Some proposals

- **Di-Higgs** (4b, bbττ)
- Low-mass Higgs bosons
- **HHH**->6b
- **TLA** Di-Jet resonance search
- Rare B-meson Decays
- LFV violating Higgs decays
- Heavy neutral leptons

* TDAQ Phase II Performance, Physics Studies, and Event Selection

Identifying Interesting Physics Scenarios

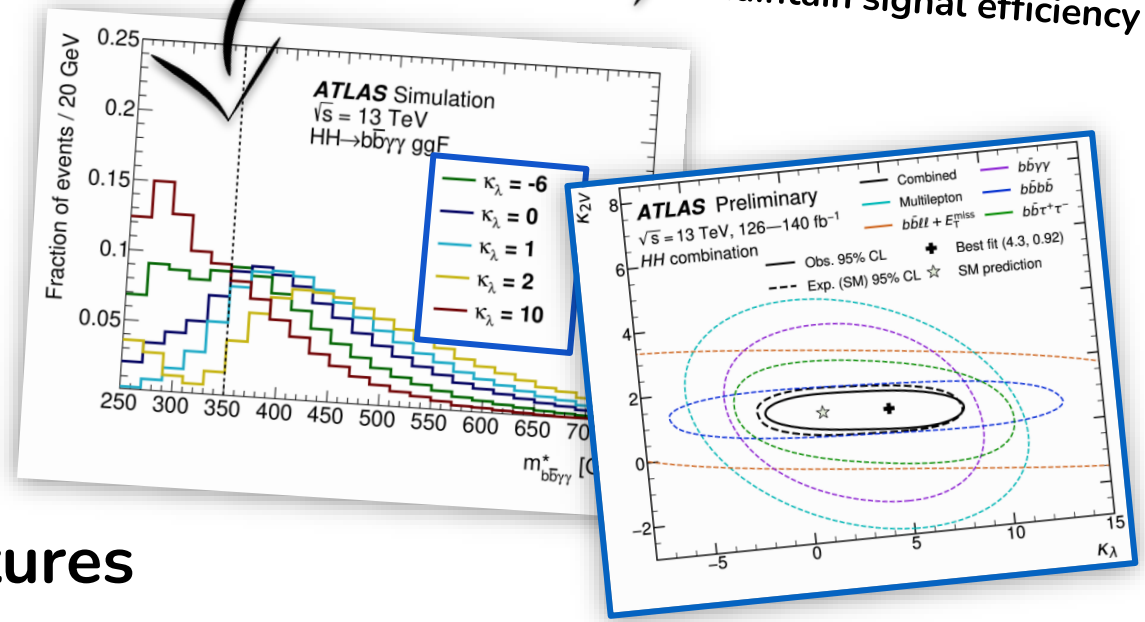
Di-Higgs

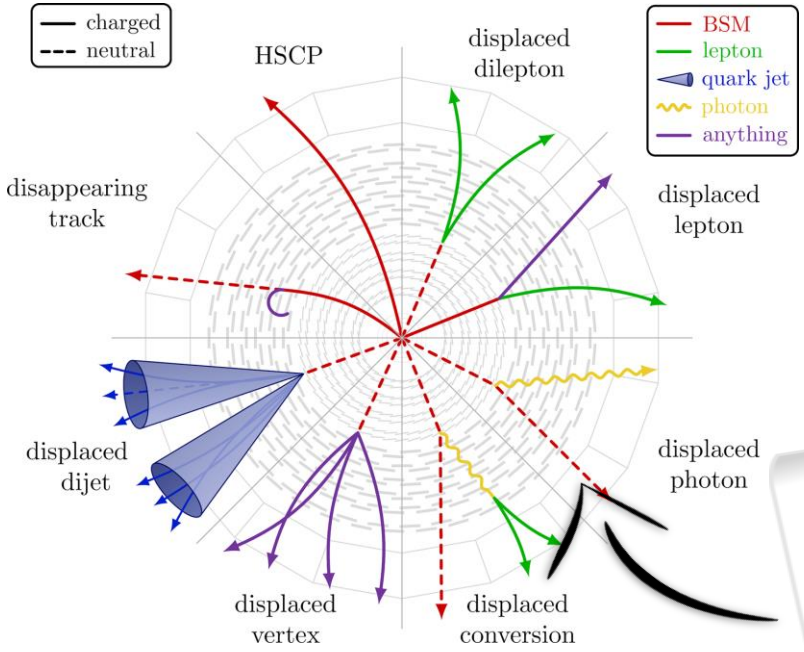
$$V(H) = \frac{1}{2}M^2H^2 + \lambda v H^3 + \frac{1}{4}\lambda' H^4$$

- Rare process – essential to characterize **self-coupling** of the Higgs
  → Fundamental parameter of the Higgs potential
- Recent advances: Potential for HH at HC-LHC **beyond original expectations → Need triggers to make the most of it**

Modifications to the self-coupling impact kinematic distribution

Develop new triggers to maintain signal efficiency



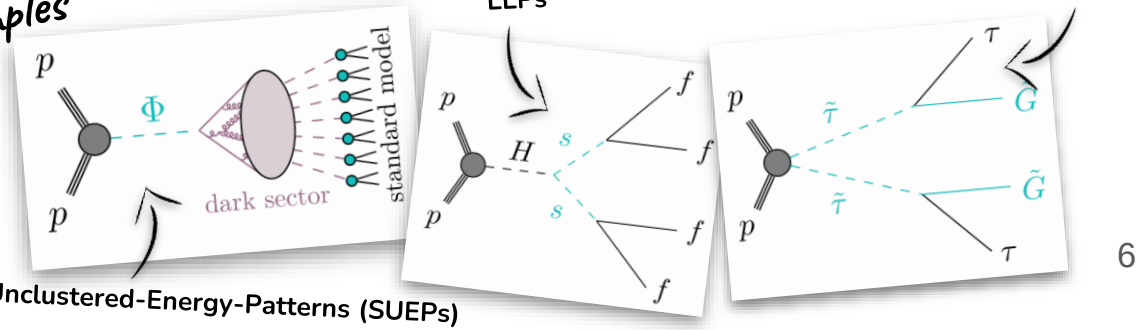


Exotic signatures

- In WP 2.7, we are particularly interested in **non-standard** signatures in the detector that require **novel trigger concepts**
- Particularly interested in **exotic** final states

Signatures for LLPs
- Time (delayed)
- Unusual Ionisation pattern
- Displacement

Examples

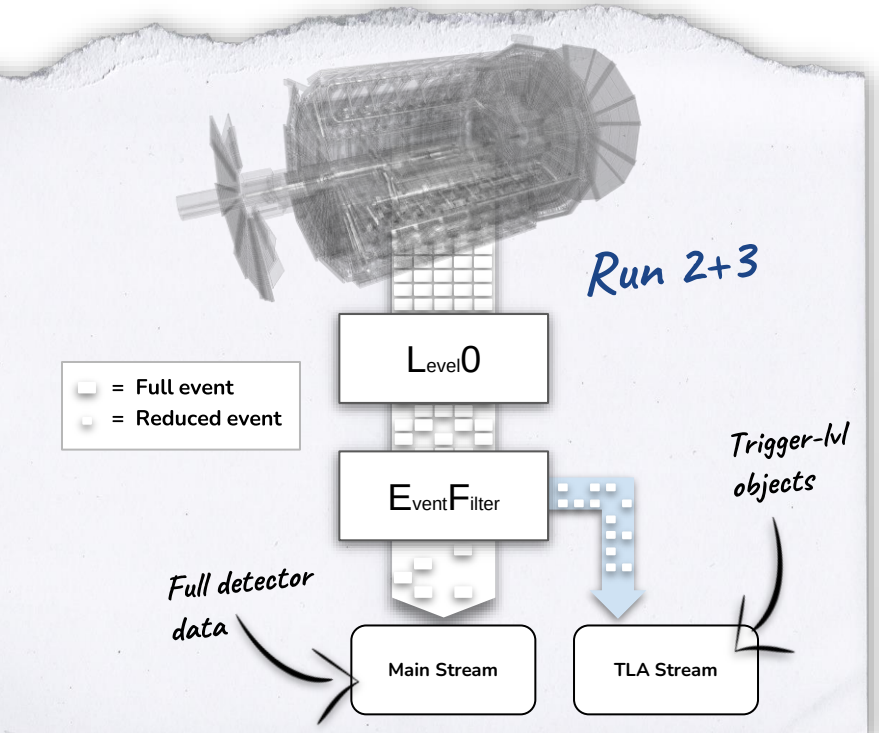


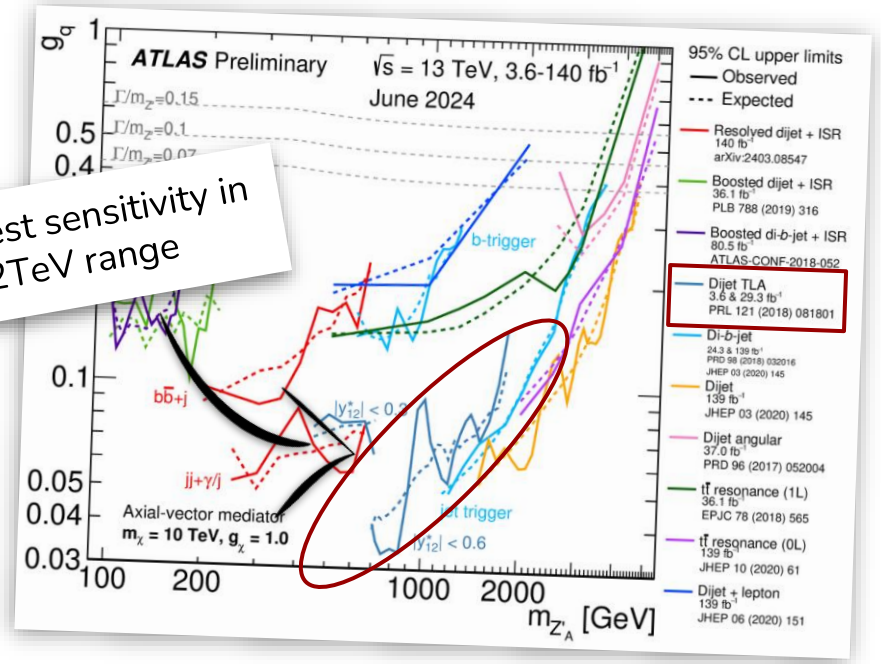
Identifying Interesting Physics Scenarios

– Trigger Level Analysis

Why do TLA

- Many BSM / exotics searches (e.g. dark matter mediators) limited by available **trigger bandwidth**
- If we can not reduce trigger rate: **Reduce event size**





TLA has best sensitivity in the 0.7-1.2TeV range

How to do TLA

- Baseline TLA workflow only stores **lightweight high-level information** from **trigger reconstruction** (HLT-jets, -photons, -muons, etc.)
- TLA Mechanism stores **robust information sufficient for analysis**, including information about shower profiles and isolation variables
  → But **not** designed to allow full “offline” reconstruction from low-level information
- **TLA** triggers operate in Run 3

- Main: $< \mathrm{BW} > = 1.6\ \mathrm{MB/evt} \times 1.5\ \mathrm{kHz} \simeq 2.5\ \mathrm{GB/s}$
- TLA: $< \mathrm{BW} > = 4.8\ \mathrm{kB/evt} \times 5\ \mathrm{kHz} \simeq 25\ \mathrm{MB/s}$

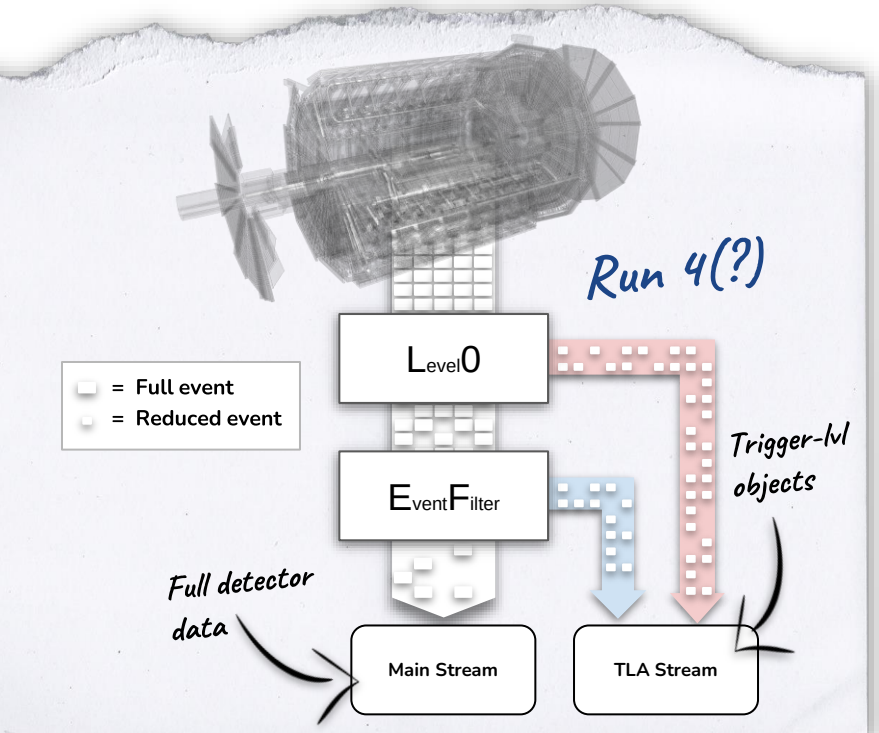
Identifying Interesting Physics Scenarios

– Trigger Level Analysis

TLA in Run-3

- Major **upgrades** between Run 2 and Run 3 - objects are saved from the HLT in the form of **trigger level jets, b-jets and photons**

- Updated **Trigger Menu** to reflect physics priorities of ATLAS, hoping to **further analyses probed by TLA in Run 2** (e.g. arXiv:1804.03496)



TLA in HL-LHC

- **Major TDAQ upgrades** will give us an exciting opportunity to exploit a heavyweight physics programme, with new ways to explore TLA

- L0-TLA use case being evaluated

- Assessment of the L0-TLA and EF-TLA **physics cases** with **sensitivity studies**

Our current effort is to evaluate the physics motivation for pursuing L0/EF-TLA in phase-II

Extensions to the Run-4 Menu & Rate Predictions

Our main objective is to extend the Run-4 trigger menu to increase the physics reach of the LHC Phase-II program

Examples

`HLT_4j100_pf_ftf_L13jJ40`

`HLT_5j50_pf_ftf_L14jJ40`

`HLT_j65c_j50c_j25c_j20c_SHARED_3j20c_bgn282_pf_ftf_L14jJ40`

We started to extend the Run-4 baseline menu (based on TDAQ TDR)
→ Addition of **new trigger chains** to profit from latest developments during Run 3

First signal acceptance studies based on

HH -> 4b (κλ = 1,10)
HH -> bbγγ (κλ = 0, 1, 2.5, 5, 10)
HH -> bbτhadτhad (κλ = 1, 10)

Initial focus on **jet triggers** for **Di-Higgs**, other (exotic) will **follow soon**

Study of background trigger rates

Simulation of **Di-Higgs** (with various BSM couplings) and **Di-Jet** events ongoing for different pile-up conditions

Trigger Selection	Run 1 Offline p_T Threshold [GeV]	Run 2 (2017) Offline p_T Threshold [GeV]	Planned HL-LHC Offline p_T Threshold [GeV]	L0 Rate [kHz]	After regional tracking cuts [kHz]	Event Filter Rate [kHz]
isolated single e	25	27	22	200	40	1.5
isolated single μ	25	27	20	45	45	1.5
single γ	120	145	120	5	5	0.3
			35	40	8	0.2

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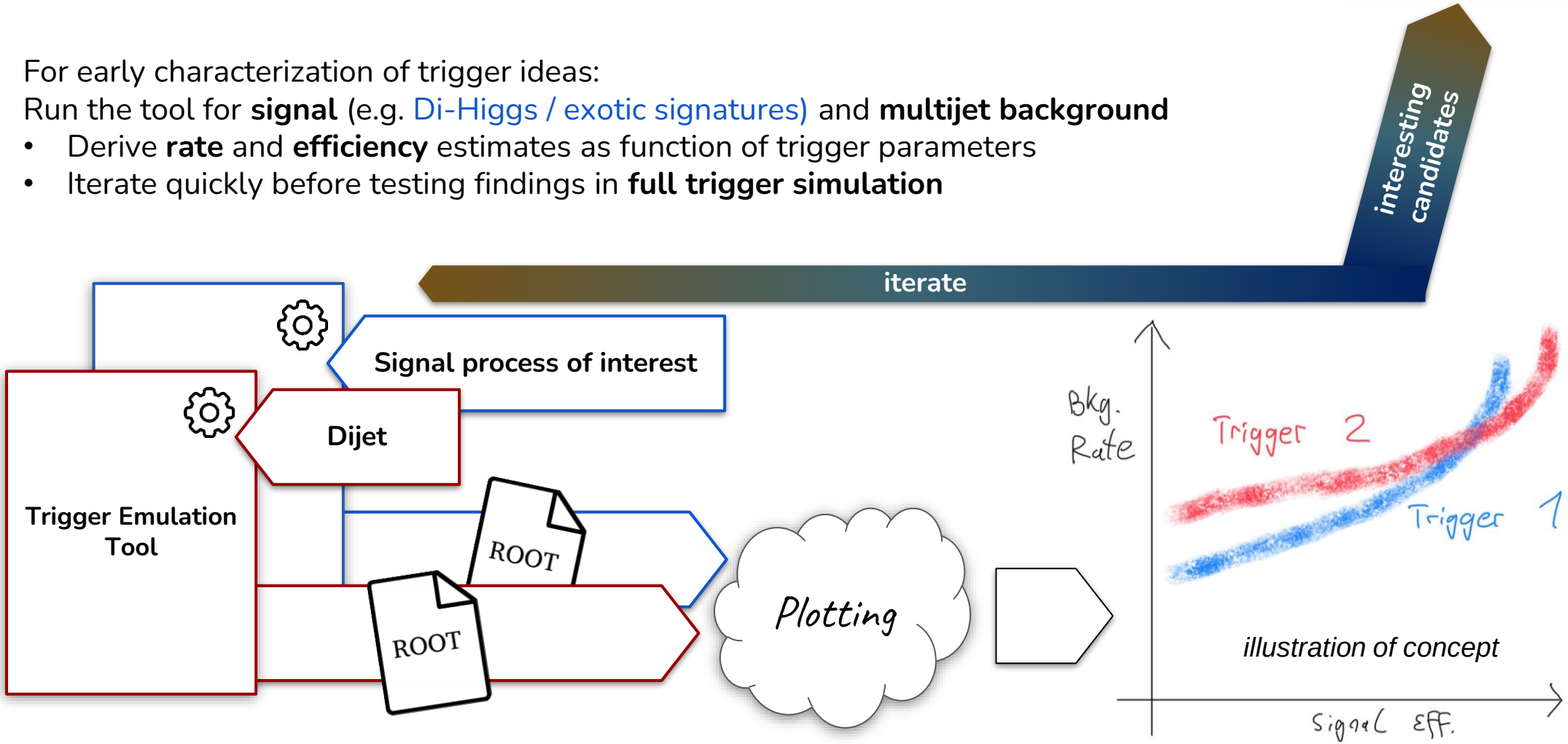
Trigger Emulation Tool

Developing **fast emulation tool** to evaluate triggers **without full menu simulation**

- Use of modified **offline reconstruction** as **proxy for trigger reconstruction**
- **Fast and flexible** definition of prototype triggers

For early characterization of trigger ideas:
Run the tool for **signal** (e.g. Di-Higgs / exotic signatures) and **multijet background**

- Derive **rate** and **efficiency** estimates as function of trigger parameters
- Iterate quickly before testing findings in **full trigger simulation**



Trigger Emulation Tool

(All) our tools are developed to be shared within the wider collaboration and NextGen

= Athena algorithm(s)

1. General

Some general configuration (event cleaning etc.)

2. Config

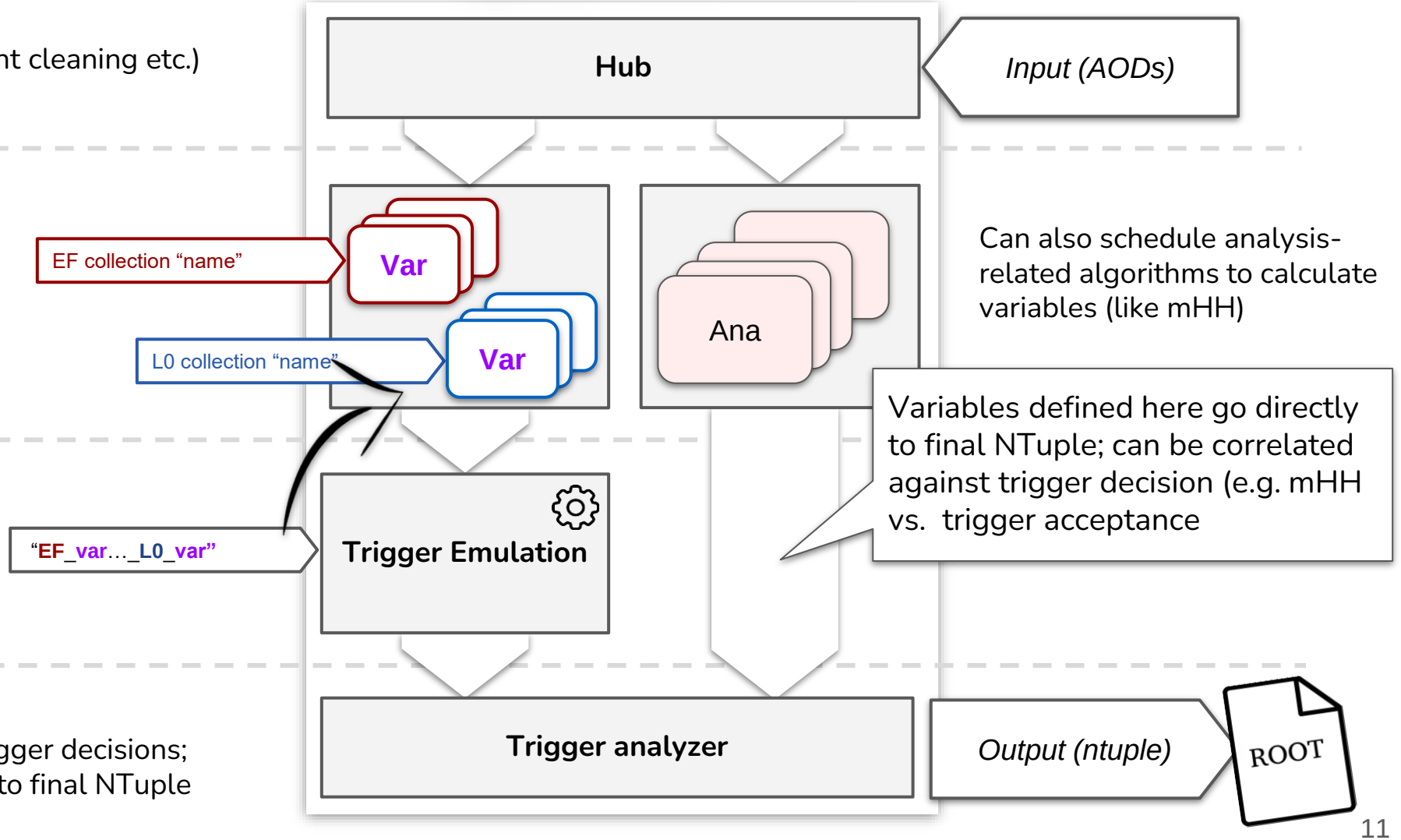
User schedules algorithms that add variables to trigger service. Those variables are part of the trigger chain(s) (**EF_var…_L0_var**) that are to be emulated.
Can include **ML discriminants**

3. Emulation

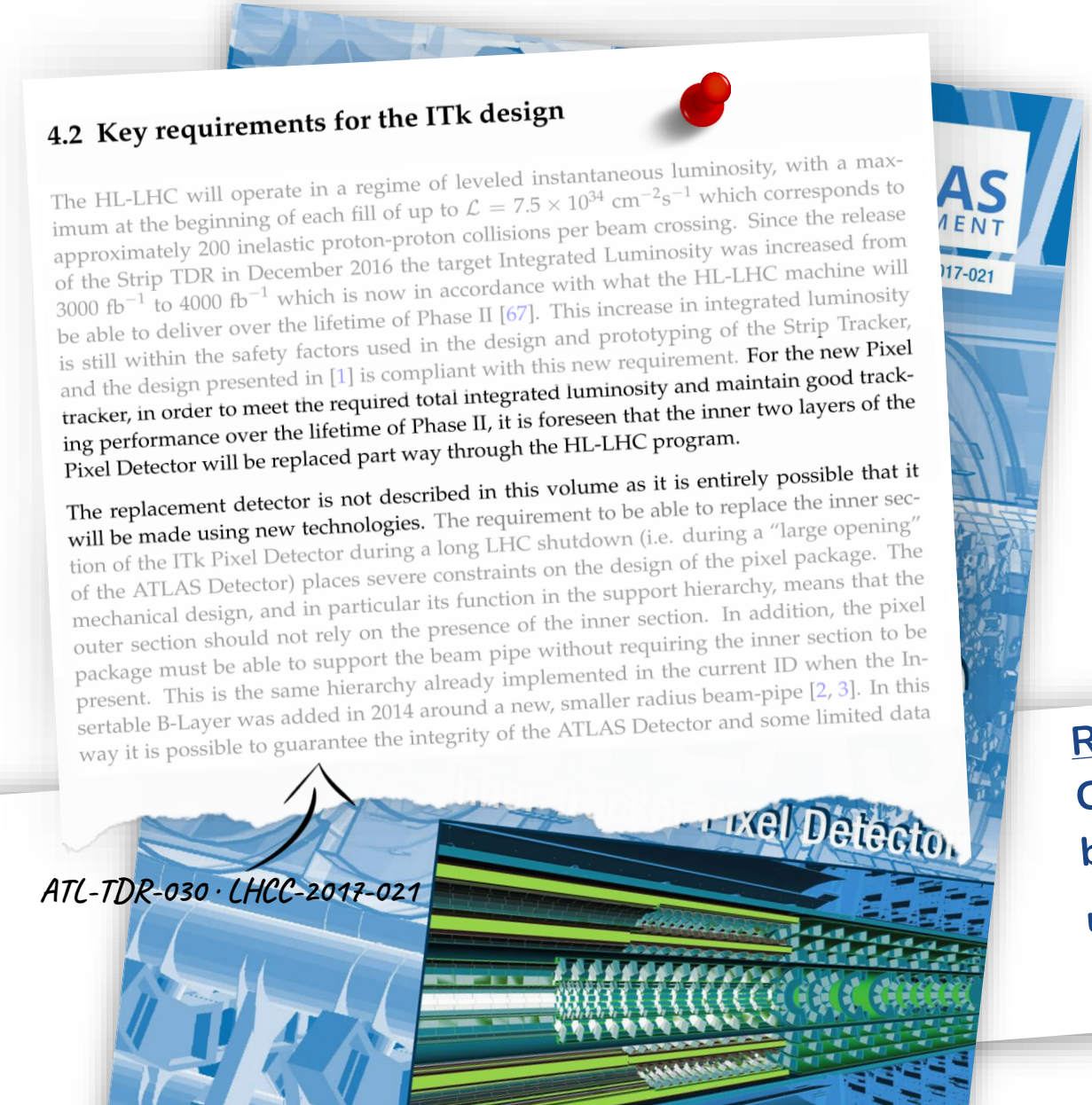
Emulate **two-level** structure as in ATLAS trigger. **First** and **second** level use different objects to mimic conditions at EF and L0 **as closely as possible**

4. Analysis

Calculate efficiencies etc.; get trigger decisions; bypass all variables from step 2 to final NTuple



NGT Studies beyond Run-4 – Trackless b-tagging



4.2 Key requirements for the ITk design

The HL-LHC will operate in a regime of leveled instantaneous luminosity, with a maximum at the beginning of each fill of up to $\mathcal{L} = 7.5 \times 10^{34}$ cm^{-2}s^{-1} which corresponds to approximately 200 inelastic proton-proton collisions per beam crossing. Since the release of the Strip TDR in December 2016 the target Integrated Luminosity was increased from 3000 fb^{-1} to 4000 fb^{-1} which is now in accordance with what the HL-LHC machine will be able to deliver over the lifetime of Phase II [67]. This increase in integrated luminosity is still within the safety factors used in the design and prototyping of the Strip Tracker, and the design presented in [1] is compliant with this new requirement. For the new Pixel tracker, in order to meet the required total integrated luminosity and maintain good tracking performance over the lifetime of Phase II, it is foreseen that the inner two layers of the Pixel Detector will be replaced part way through the HL-LHC program.

The replacement detector is not described in this volume as it is entirely possible that it will be made using new technologies. The requirement to be able to replace the inner section of the ITk Pixel Detector during a long LHC shutdown (i.e. during a "large opening" of the ATLAS Detector) places severe constraints on the design of the pixel package. The mechanical design, and in particular its function in the support hierarchy, means that the outer section should not rely on the presence of the inner section. In addition, the pixel package must be able to support the beam pipe without requiring the inner section to be present. This is the same hierarchy already implemented in the current ID when the Insertable B-Layer was added in 2014 around a new, smaller radius beam-pipe [2, 3]. In this way it is possible to guarantee the integrity of the ATLAS Detector and some limited data

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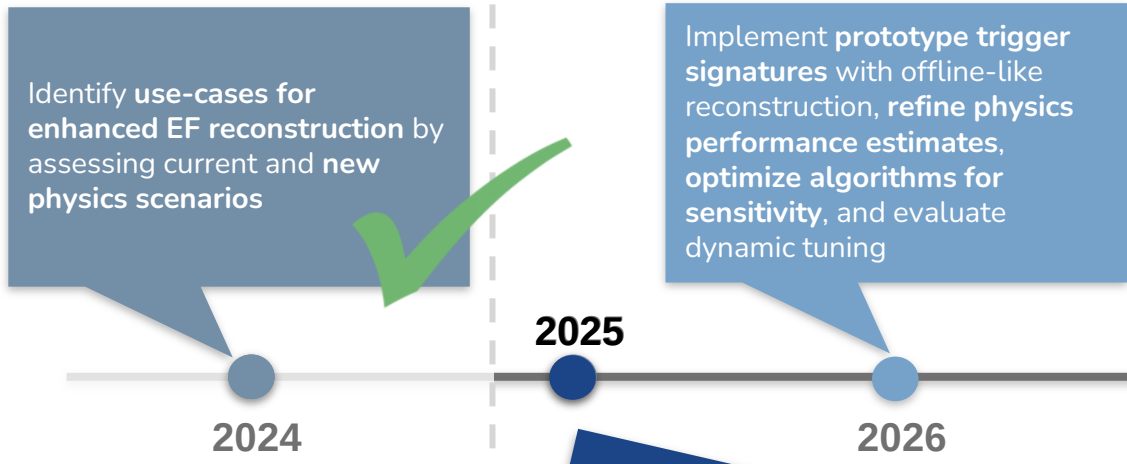
The innermost two layers of the ITk must (quote) *„[…] be replaced after part way through the HL-LHC program.“*

- **Assuming** new ITk pixel sensors would provide timing measurement (starting ATL-PHYS-PUB-2023-023 where 4D tracking was studied) to help discriminate signal from pile-up hits
- **Assuming** a new readout technology that would allow to read the new Innermost Layers at a rate > 1MHz
- **R&D question: Feasibility** of **b-tagging** mechanism **before EF** using L0-L1 trigger scheme?

R&D study in WP 2.7:
Can we do some kind of (trackless) b-tagging (e.g., utilizing a GNN) using *only the* two *innermost layers* of the ITk?

WP 2.7 – Plans for 2025

As 2024 draws to a close, what lies ahead



Characterize potential gains to **select key signatures** for implementation, **emulate ideal trigger performance**, and establish a **dynamic bandwidth allocation** framework

- Make final decision on baseline processes and key signatures and start developing prototype chains
- Emulate trigger performance (signal acceptance & background rejection) and estimate trigger rates
- Start investigating dynamic bandwidth allocation
- Investigate TLA and other real-time analysis methods

With most preparatory work being done, we can finally start doing cool stuff!

Summary

- Main objective of WP 2.7 is to extend the Run-4 trigger menu to increase the physics reach of the HL-LHC
- Priorities of 2024: **hiring, building tools, integration into ATLAS, Identify interesting signatures/processes**
- First processes and signatures have been identified; simulation of samples initialized
- Currently investigating physics potential of TLA and different techniques like anomaly detection
- First modifications to Run-4 trigger menu for preliminary trigger rate and acceptance studies
- Feasibility study of trackless b-tagging beyond Run-4

Outlook

- Finalize baseline processes and key signatures
- Emulate trigger performance (signal acceptance & background rejection) and estimate trigger rates
- Start developing a dynamic bandwidth allocation framework to automate calculation of pre-scale factors

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