Tracking in the L1 Trigger

for the ATLAS & CMS phase-2 upgrades

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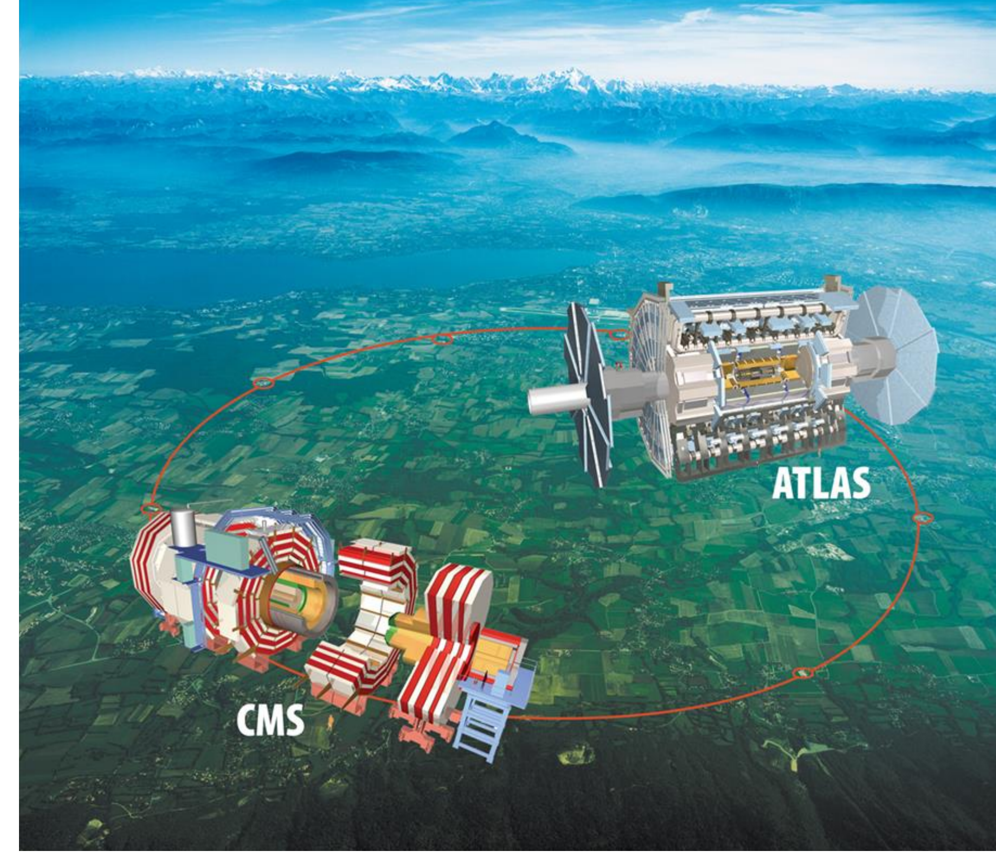
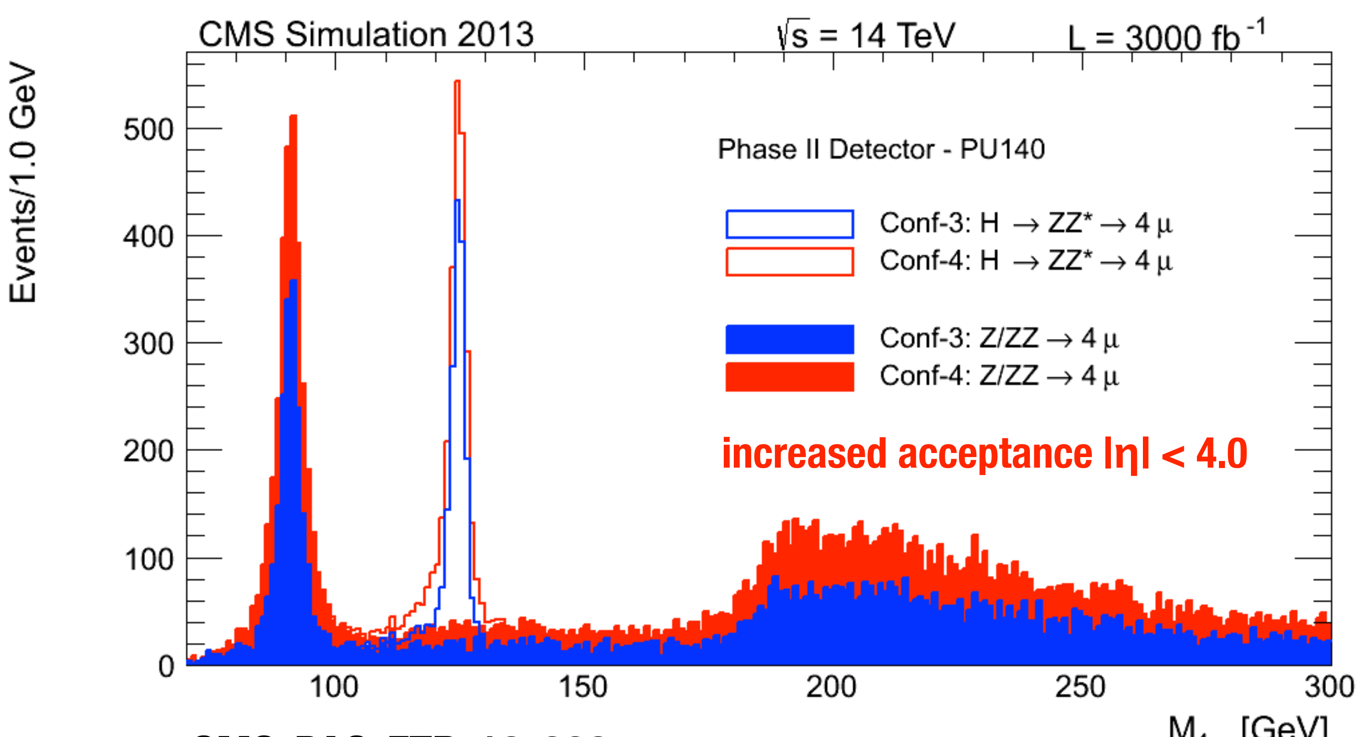
on behalf of the ATLAS & CMS collaborations

Physics at LHC and Beyond, Quy-Nhon, Vietnam, 10-17 August 2014

High-Luminosity LHC



- Upgrade to High-Luminosity LHC (HL-LHC) foreseen for 2023-2025
  - Peak luminosity **5x10^{34} cm^{-2}s^{-1}**
  - Goal of **3000 fb^{-1}** (10 years)
- Physics motivation
  - Precision measurements of Higgs properties, couplings & rare decays
  - Higgs self-coupling
  - Searches for SUSY & other BSM scenarios, rare processes, ...



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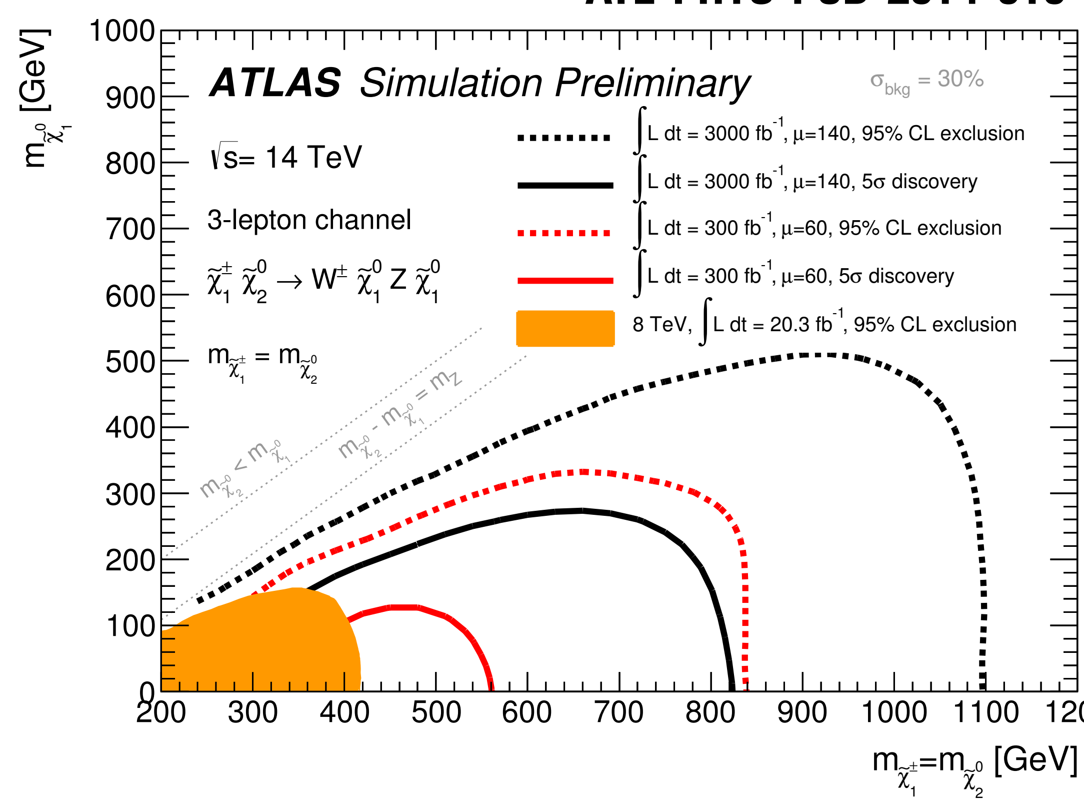
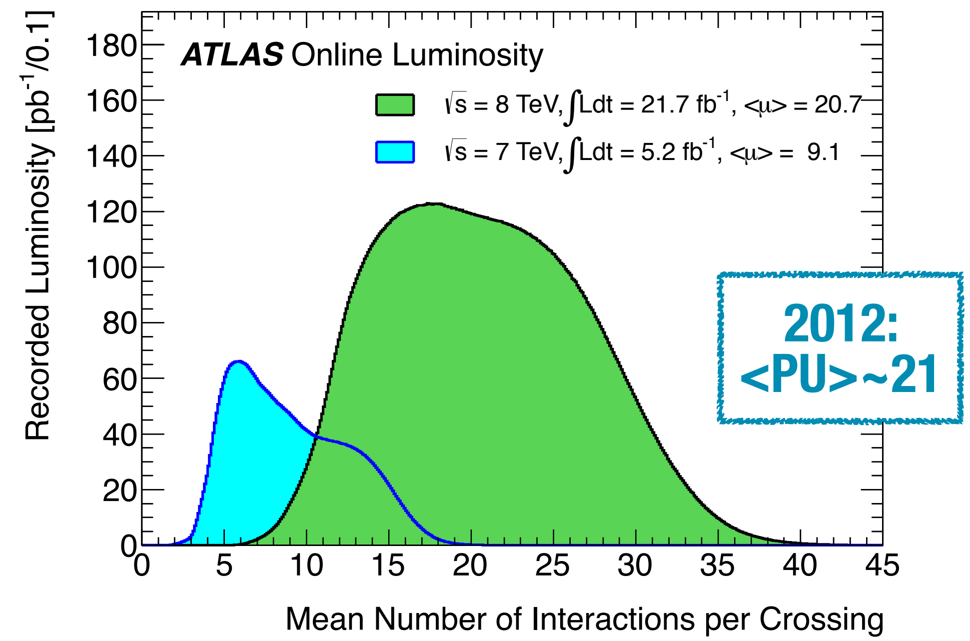


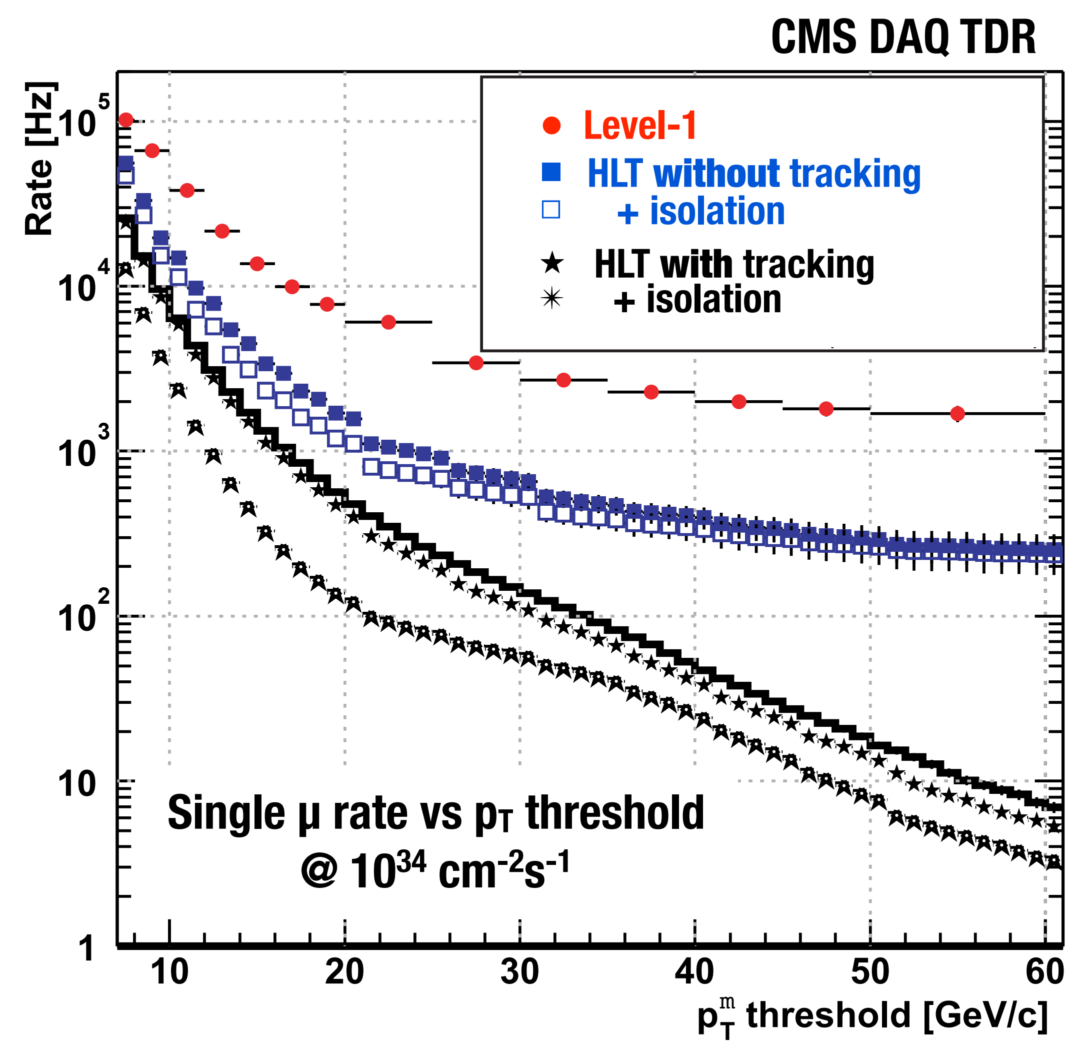
Why Tracking @ L1?

- Price for high instantaneous luminosity: **<PU>=140**, reaching up to 200
- Physics goals rely on continued excellent detector performance & **trigger capabilities**
  - Must allow triggering on objects at EW scale
- With HL-LHC, single μ, e, jet rates would exceed 100 kHz



Increasing thresholds limits physics potential + alone insufficient!

⇒ **Tracking @ L1**



Tracking @ L1: **Overview**

- Different approaches to incorporating tracking in L1 trigger
  - Region-of-interest (ATLAS)
  - Self-seeded tracking (CMS)
    - *Impacts tracker detector design*

- Technologies
  - Associative memory (AM) chip pattern recognition (ATLAS, CMS)
  - Tracking using FPGAs with tracklet-based approach (CMS)

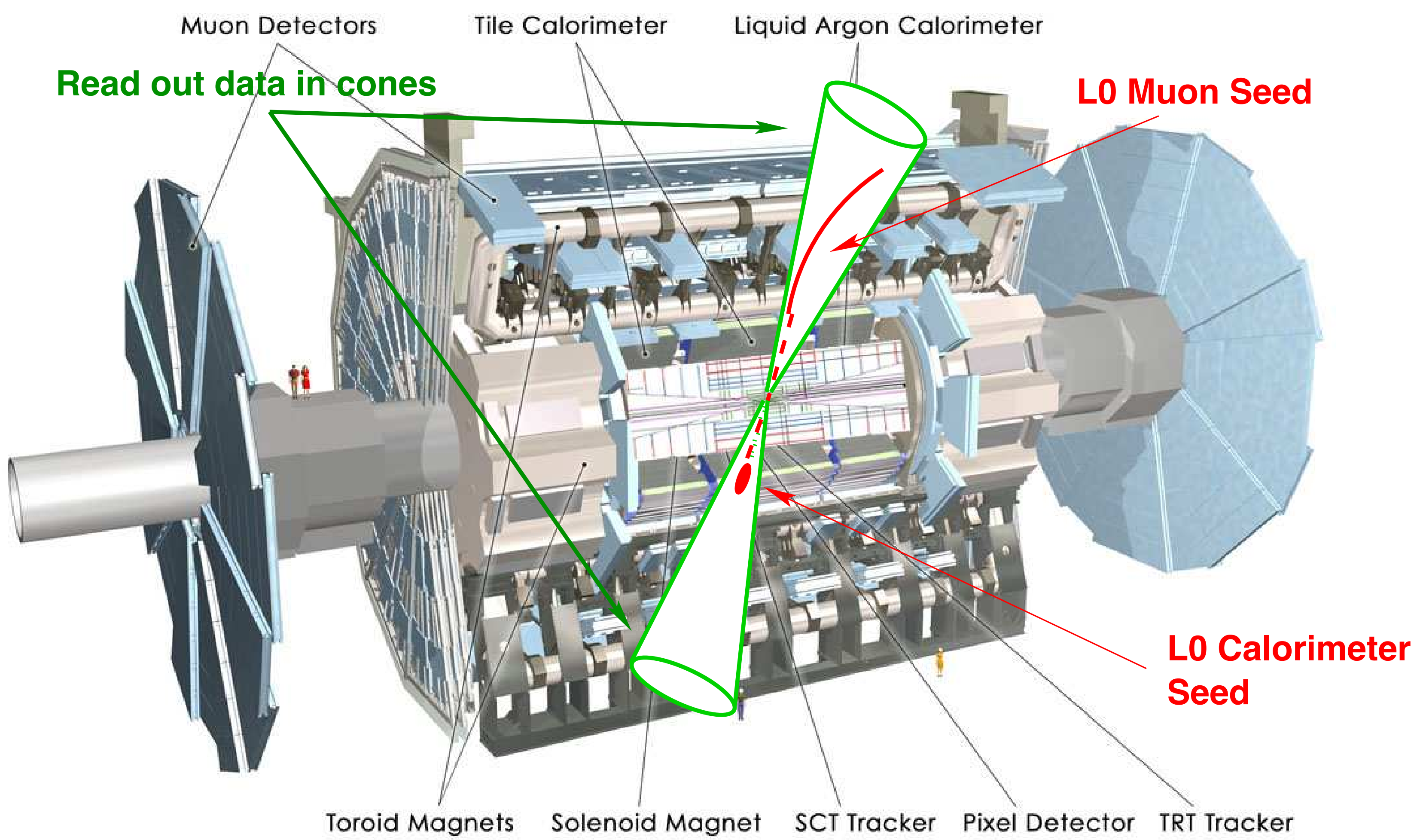
- **With either approach, must combine L1 tracks with L1 objects for use in trigger!**

Tracking @ L1: **ATLAS**

- **Region of Interests (RoIs)**
  - Split current L1 into two levels: **L0 (old L1) + new L1**
  - L0 provides RoIs (calorimeter & muon seeds) for new L1
  - Partial tracker readout for RoI track finding, full readout at reduced rate
    - *RoIs correspond to max ~10% of entire detector*

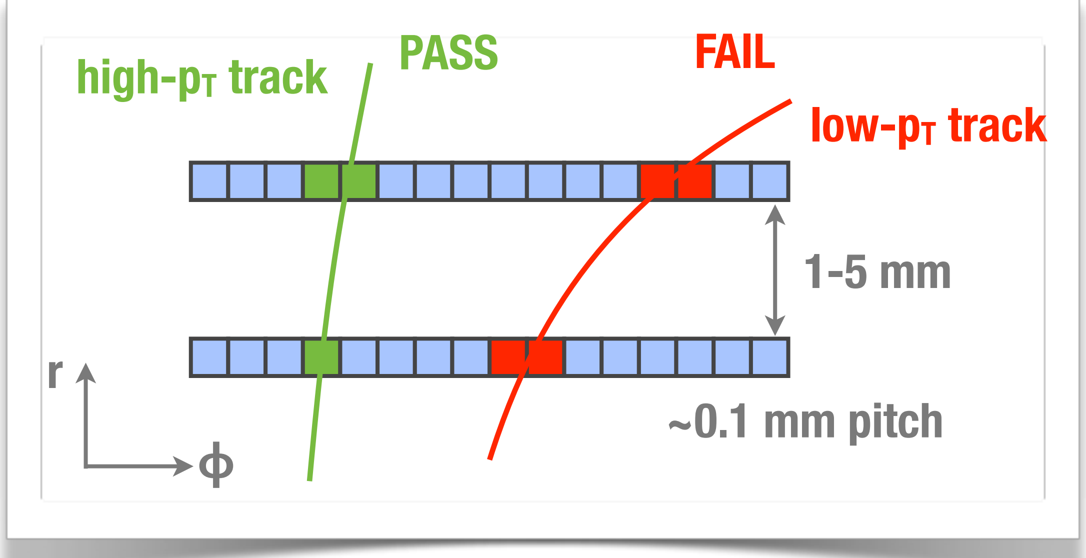
- Baseline trigger architecture
  - L0 readout up to 1 MHz, 6 μs latency
  - L1 readout up to 400 kHz, 30 μs latency

- Alternative self-seeded trigger considered as option in Phase-2 LoI, but not implemented in baseline tracker design



Tracking @ L1: **CMS**

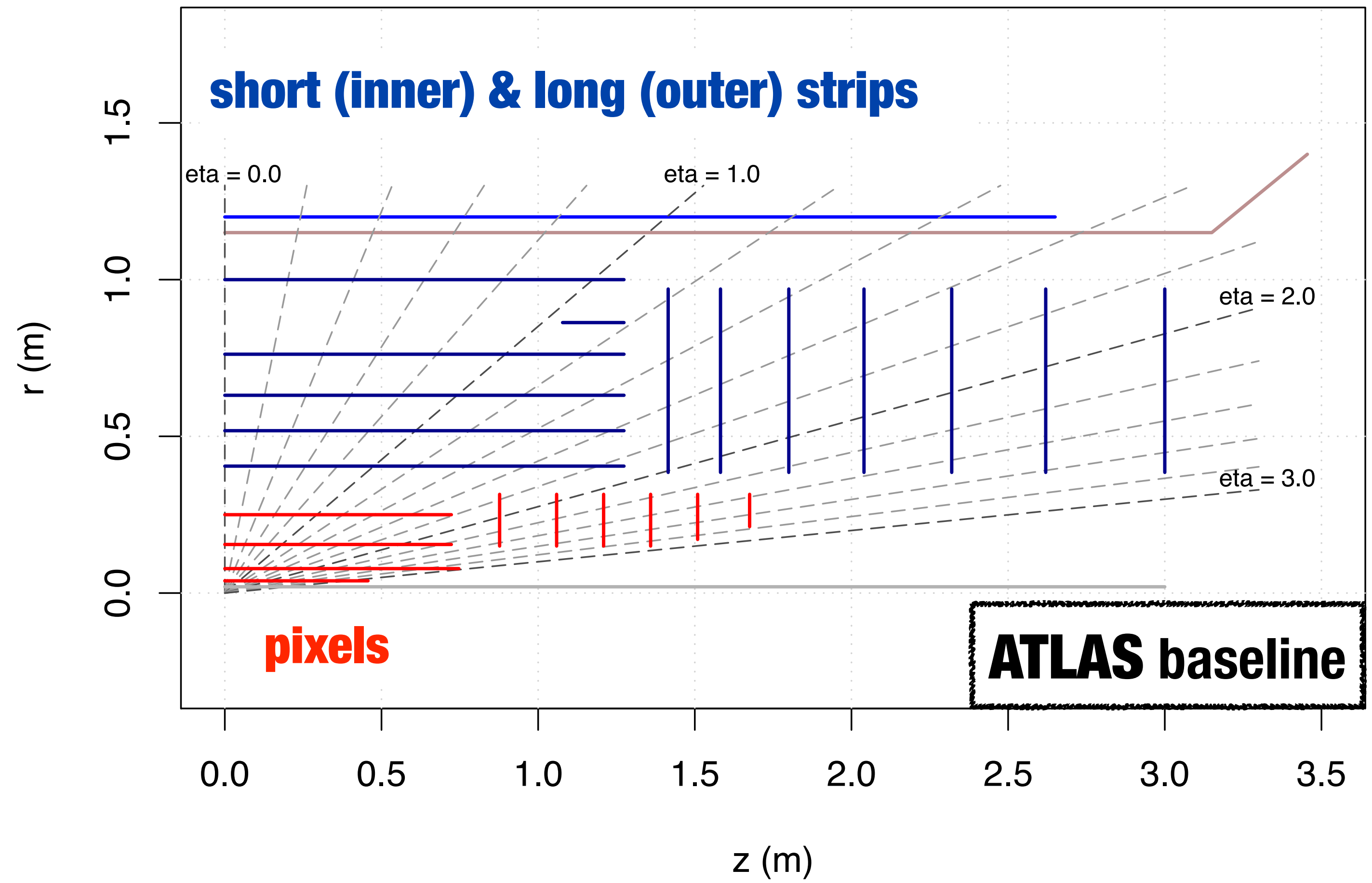
- **Self-seeded trigger**
  - Local p_T reconstruction
  - Take advantage of strong CMS magnetic field (~4T)
  - **Goal:** Find tracks with $p_T > 2$ GeV & identify z positions with ~1mm precision
    - *Similar to average vertex separation at PU=140*
- **p_T modules:** p_T discrimination through hit correlations between closely spaced sensors
  - **Stubs:** Correlated pairs of hits, consistent with 2 GeV track
    - *In minimum-bias events, 95% of tracks have $p_T \leq 2$ GeV*
  - Data reduction of O(10) at stub level
- Trigger architecture
  - L1 readout @ 500 kHz - 1 MHz with 10-20 μs latency

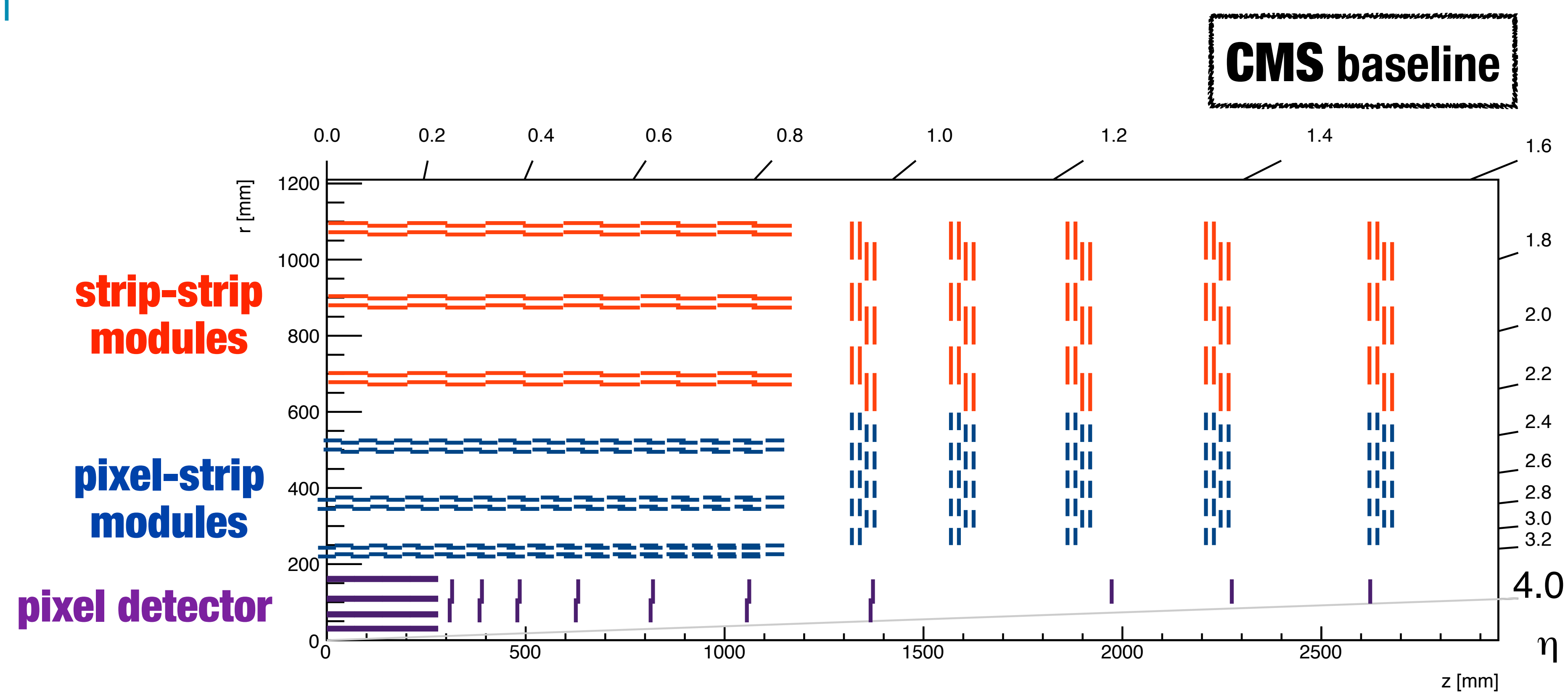


Tracker Layouts

- Replace inner tracking systems to handle HL-LHC conditions
  - Radiation hard sensors
  - Finer granularity to keep occupancy low
  - Reduce material to improve performance
  - Data rate saturates available FE readout bandwidth
- All-silicon detectors

ATLAS Phase-2 LoI





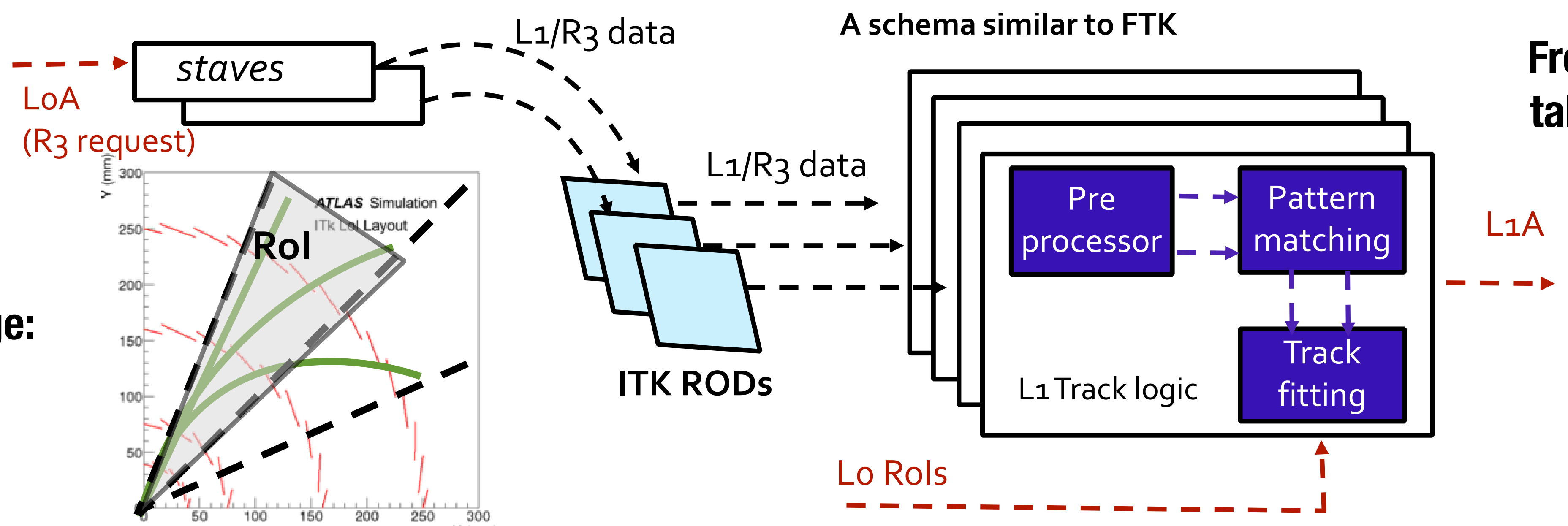
not used in L1 track-triggering

http://mersi.web.cern.ch/mersi/layouts/.current/

L1 Tracking: **Region-of-Interests (ATLAS)**

- L0 accept → Regional Readout Request (R3) to relevant FEs, sends data to RODs → Sent to L1 Tracking

Typical RoI coverage:
$\Delta\eta \times \Delta\phi$=0.3x0.3



From T. Martin's talk @ WIT2014

- L1 tracking follows ATLAS FTK principle
  - Pattern recognition with **associative memory (AM) chips**, track fitting using FPGAs
  - **FTK:** 8000 AM chips, 10^9 patterns
- L1 tracking vs FTK
  - Shorter latency
  - Higher PU + larger number of silicon layers requires many more stored patterns

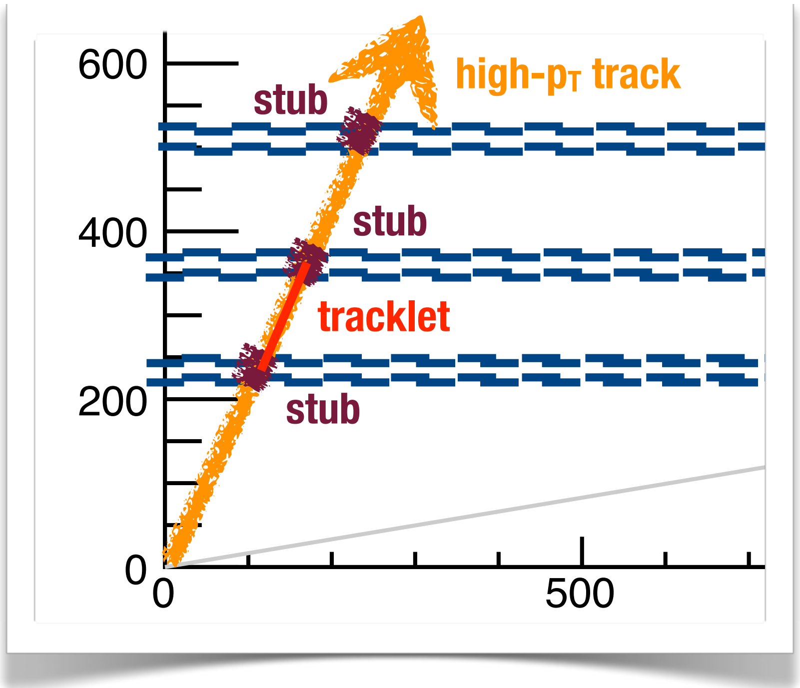
ATLAS Fast Tracker (FTK) to provide pre-fitted tracks for HLT in phase-1

L1 Tracking: **Self-Seeded (CMS)**

- Different approaches to L1 track finding, all using **stubs** as input

- **Associative memories**
  - Pattern-recognition with AM chips
    - *Stored "roads" filled with matching stub data*
  - Several track fitting methods studied
    - *Principle Component Analysis, Hough transform, Retina*

- **Tracklet method**
  - Use FPGAs to implement track finding @ L1
  - **Seed** by forming tracklets from pairs of stubs
  - **Project** to other layers/disks
  - **Fit** stubs matched to trajectory for track parameters (using linearized χ^2 fit)

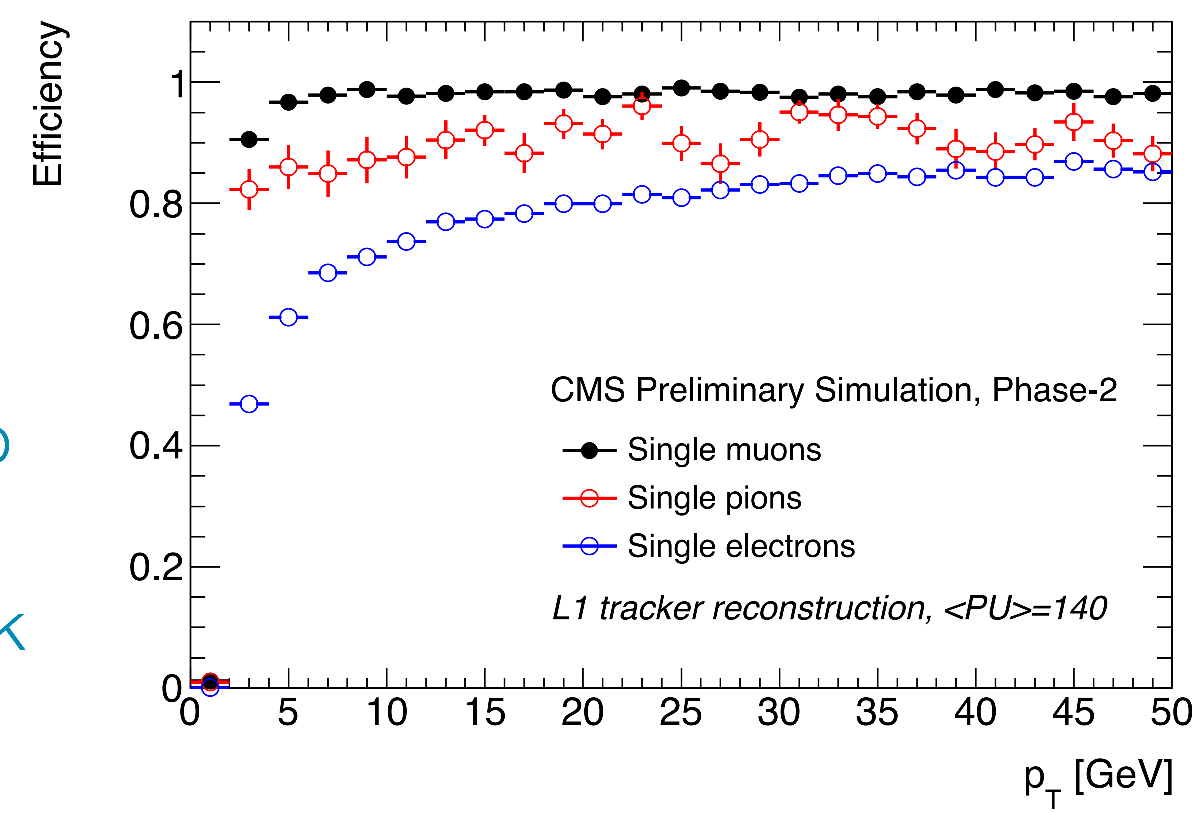


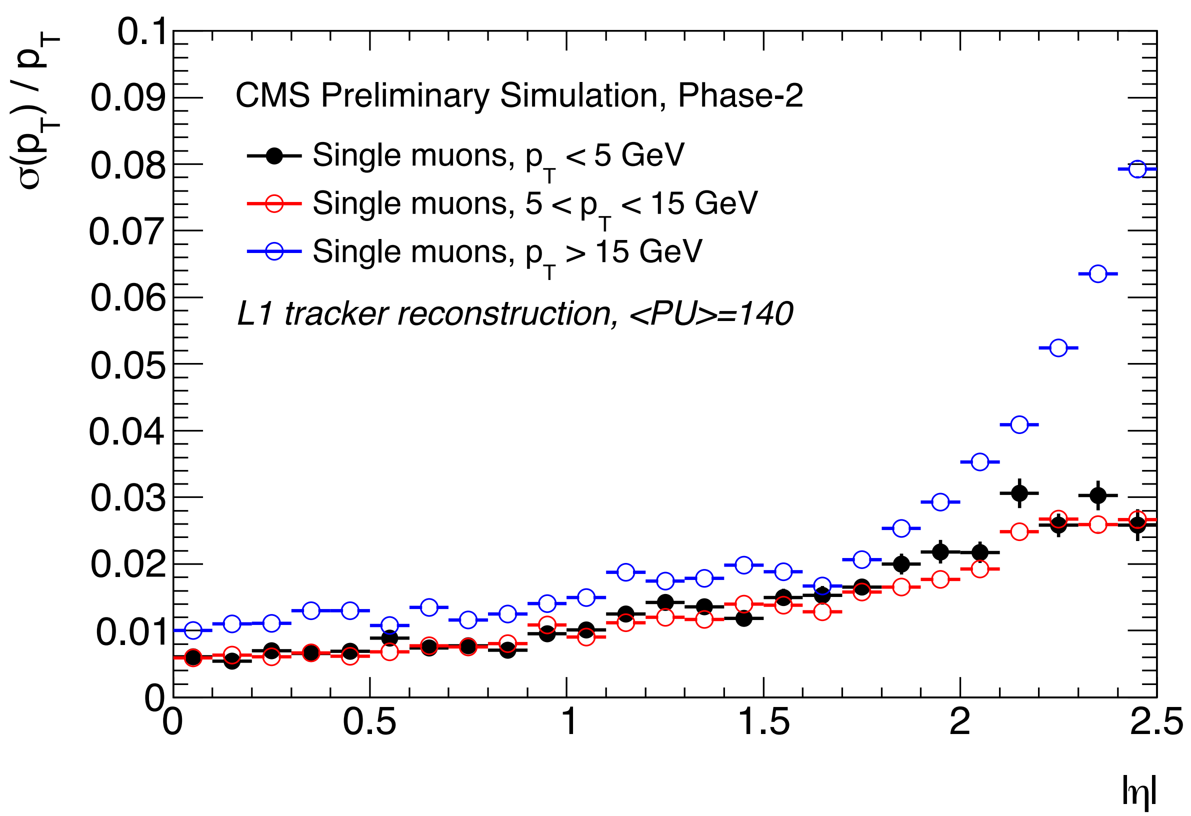
- Evaluate expected L1 tracking performance using simulation

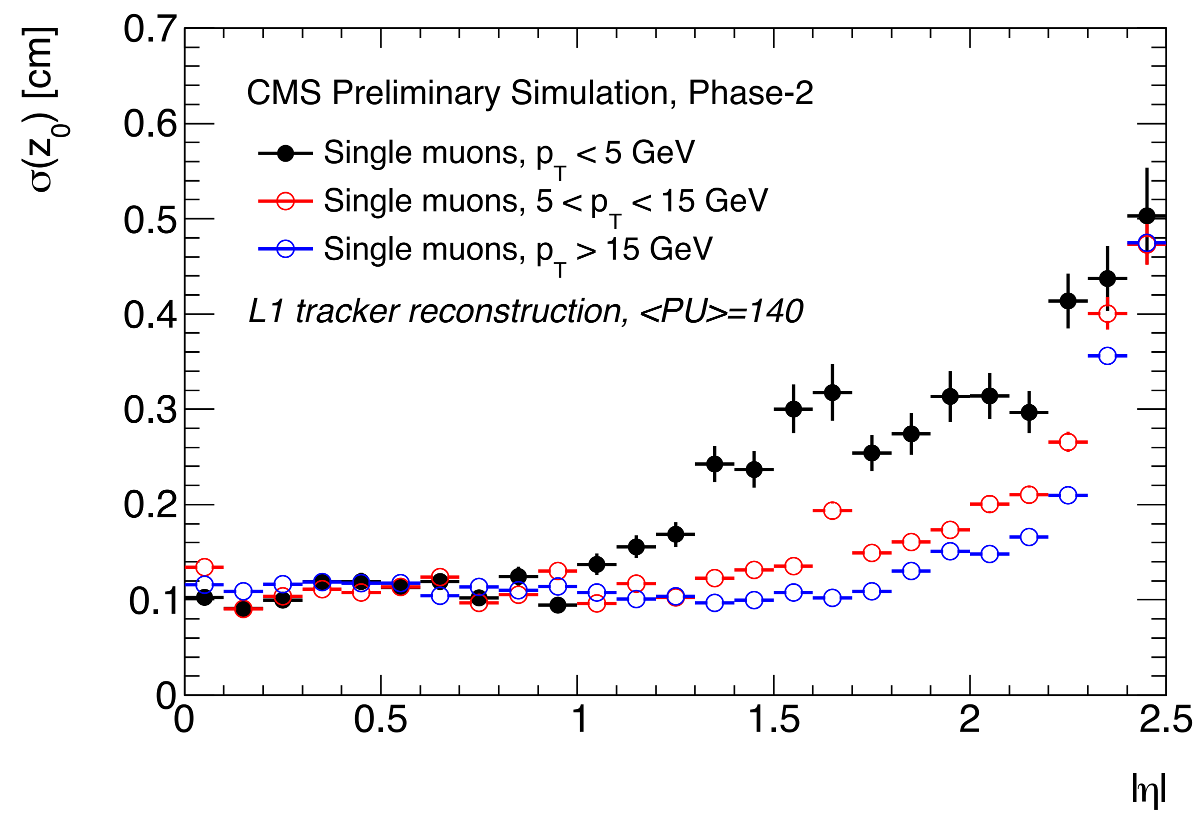
L1 Tracking: **Performance (CMS)**

Shown for tracklet-based approach

- 99% efficiency for single muons
  - Lower efficiency for electrons, affected by brehmsstrahlung
- Resolutions
  - **$\sigma(z_0)$~1mm** for wide range of η thanks to PS modules
  - **$\sigma(p_T)/p_T$~1%** at central η for high-p_T track







Toward Triggers

- How does L1 tracking help reduce trigger rates?
  - **Leptons...**
    - *Matching L1 objects to L1 tracks*
      - Improved p_T measurements
      - Determine z positions
    - *Add track isolation*
  - **Photons...**
    - *Add track isolation*
  - **Hadronic...**
    - *Determine jet z positions*
    - *Require jets to originate from common vertex to reject jets from PU interactions*
  - **Primary vertex & track MET**

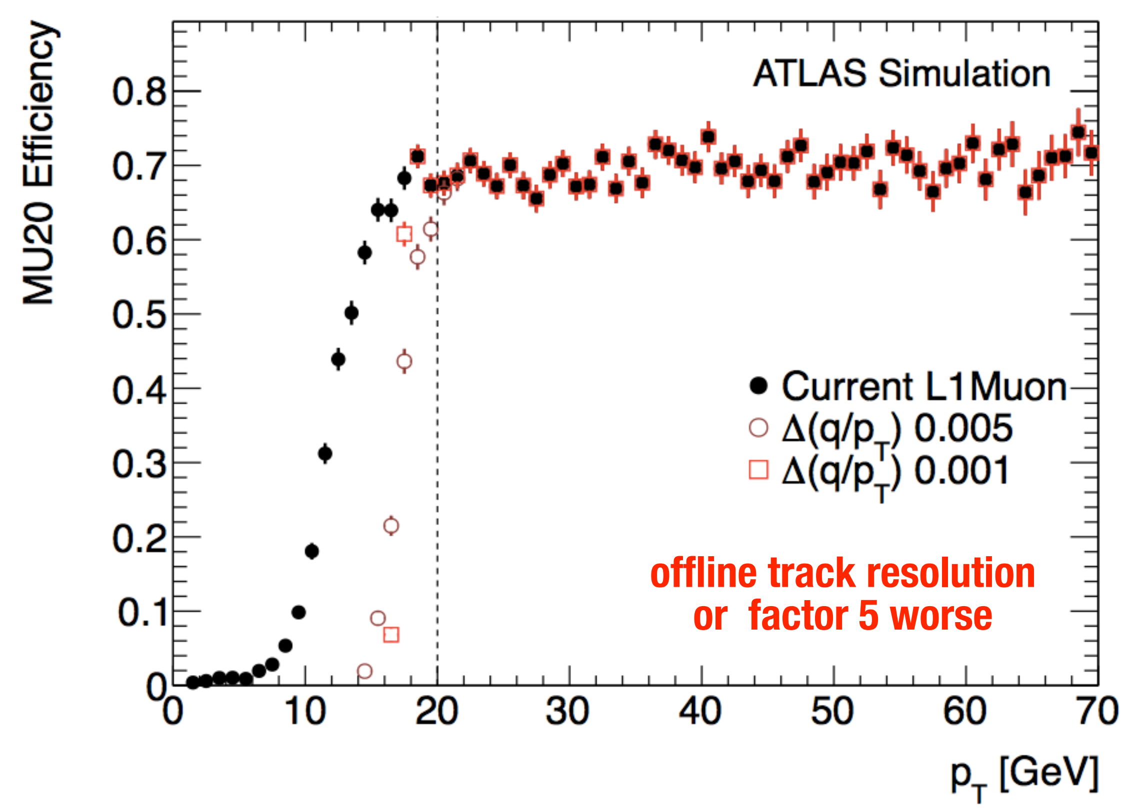
Using L1 Tracks: **e/μ (ATLAS)**

- Significant rate reductions for single-lepton triggers w.r.t. L0 rate
  - Muon p_T turn-on curve sharpened
  - Track-matched EM trigger rejects background from EM energy deposits from $\pi^{\pm}$ & photons from π^0
    - *Factor ~5 in rate single e/μ trigger*

ATLAS Phase-2 LoI Draft Trigger Menu

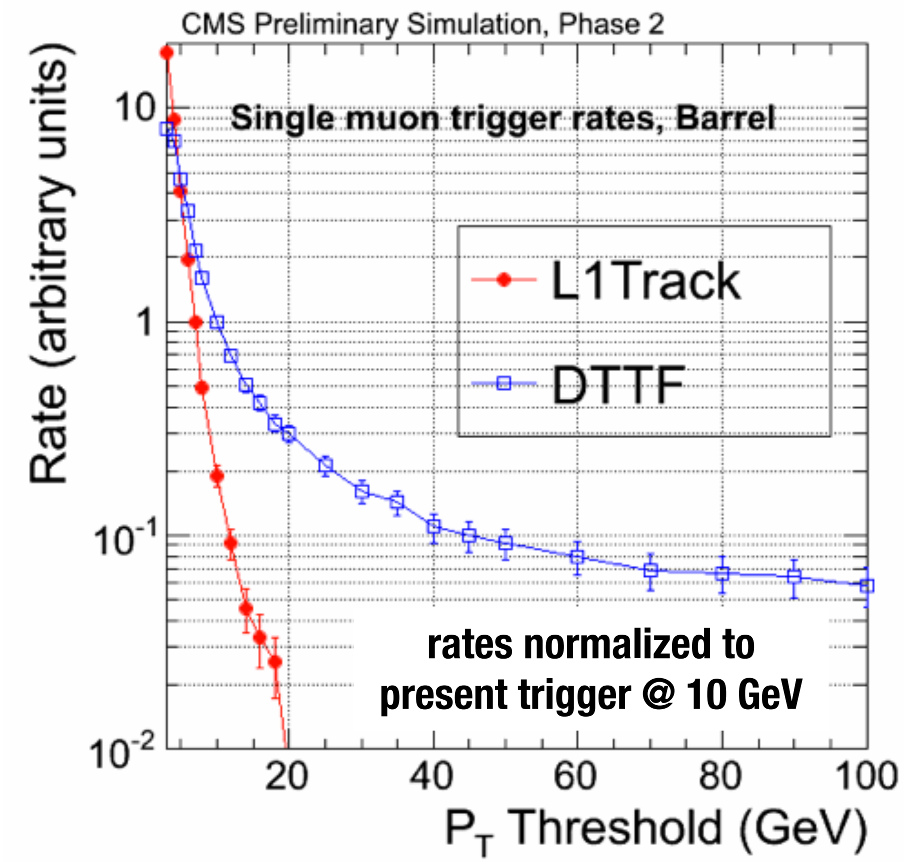
Object(s)	Trigger	Estimated Rate	
		no L1Track	with L1Track
e	EM20	200 kHz	40 kHz
γ	EM40	20 kHz	10 kHz*
μ	MU20	> 40 kHz	10 kHz
τ	TAU50	50 kHz	20 kHz
ee	2EM10	40 kHz	< 1 kHz
$\gamma\gamma$	2EM10	as above	~5 kHz*
$e\mu$	EM10_MU6	30 kHz	< 1 kHz
$\mu\mu$	2MU10	4 kHz	< 1 kHz
$\tau\tau$	2TAU15I	40 kHz	2 kHz
Other	JET + MET	~ 100 kHz	~ 100 kHz
Total		~ 500 kHz	~ 200 kHz

ATLAS Phase-2 LoI

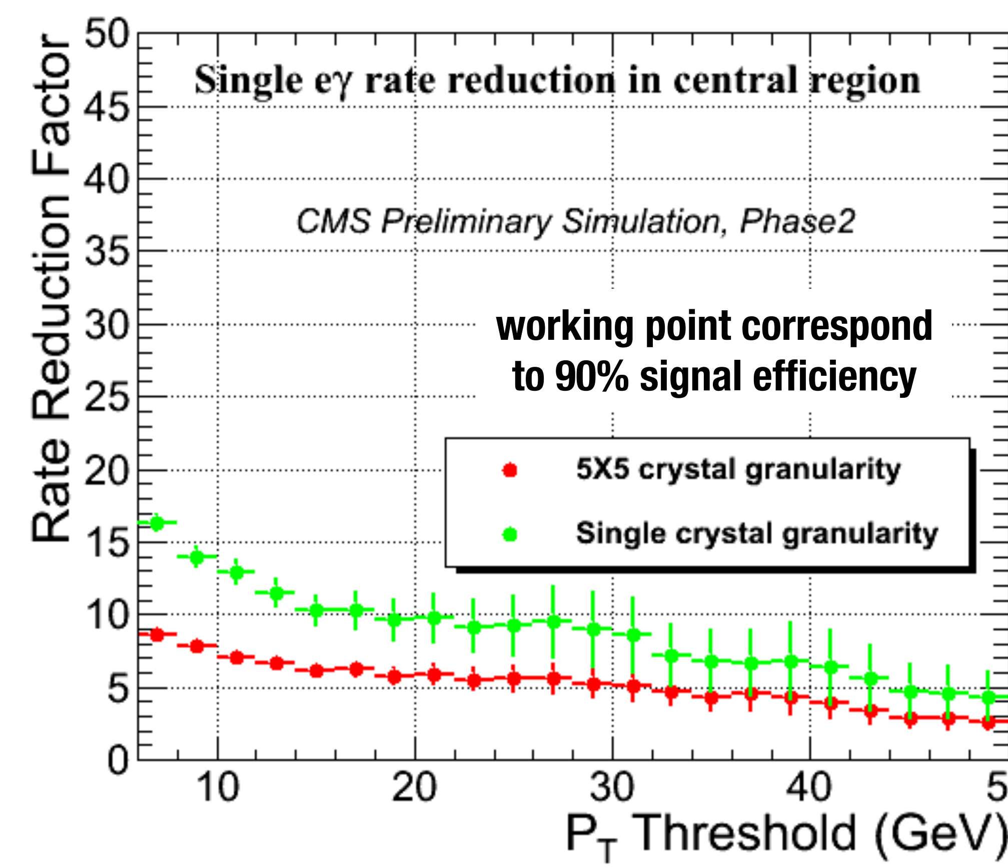


Using L1 Tracks: **e/μ (CMS)**

- **Muons**
  - Rates flatten at high thresholds
  - Matching to L1 tracks → factor >10 reduction for p_T > 14 GeV (w/o track isolation)



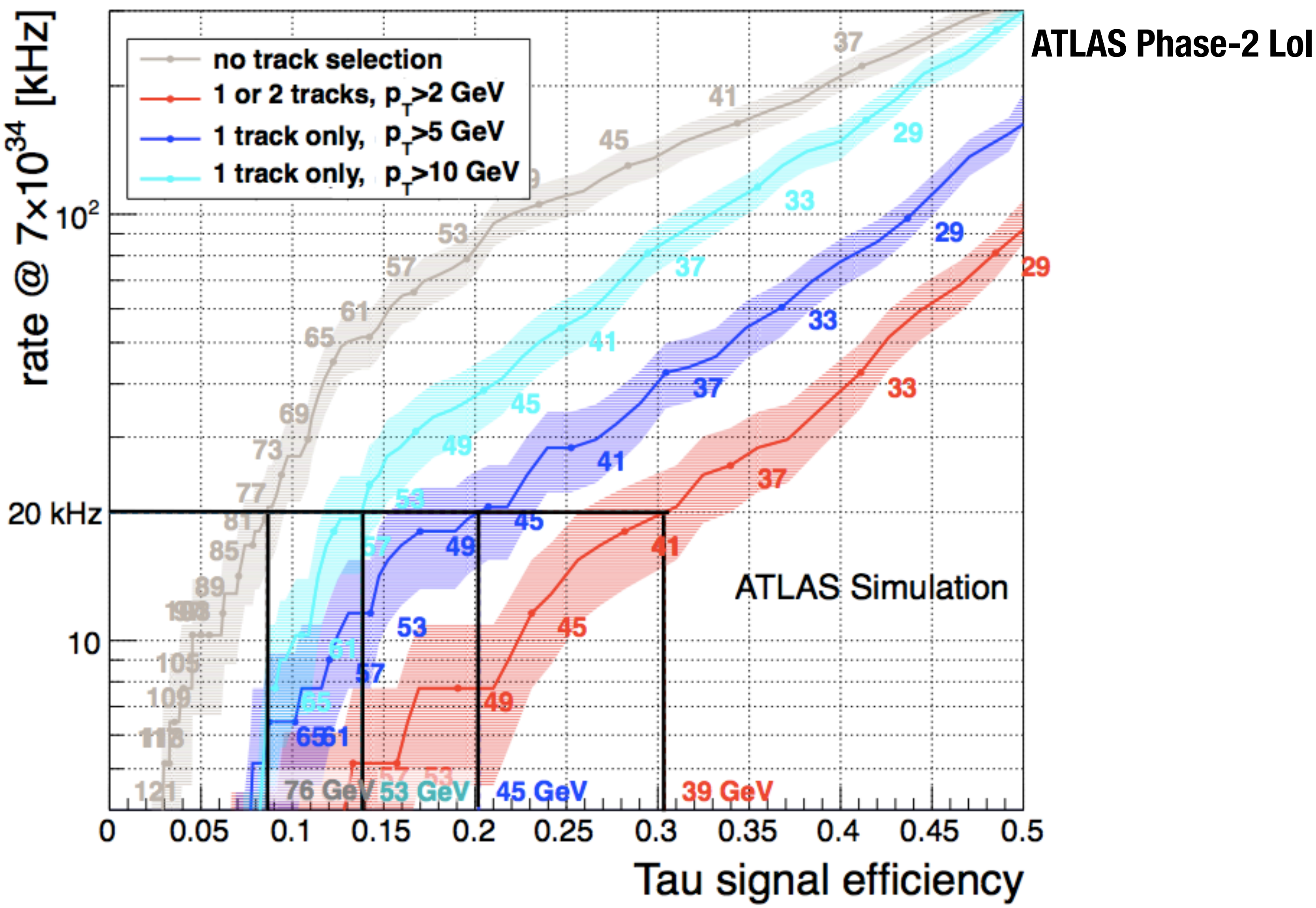
- **Electrons**
  - Match L1 e/γ objects to stubs
  - Factor **~10 (~6)** rate reduction for **single (current 5x5)** crystal granularity @ 20 GeV



- *Additional factor ~2 rate reduction with L1 track-based isolation*

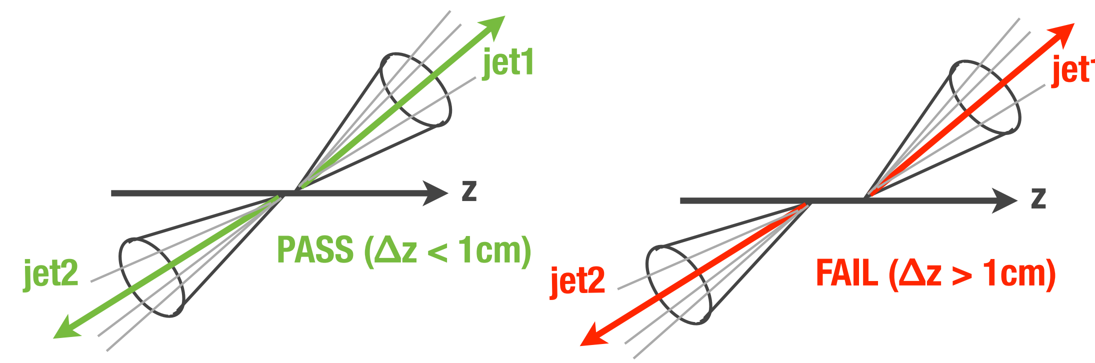
Using L1 Tracks: **Taus (ATLAS)**

- Rate vs L1 tau finding efficiency for taus from 120 GeV Higgs signal
- Single L1 tau trigger @ 20 kHz
  - **Without tracking:** 79 GeV threshold - 8% signal efficiency
  - **With 1-2 tracks (p_T > 2 GeV):** 39 GeV threshold - 30% signal efficiency

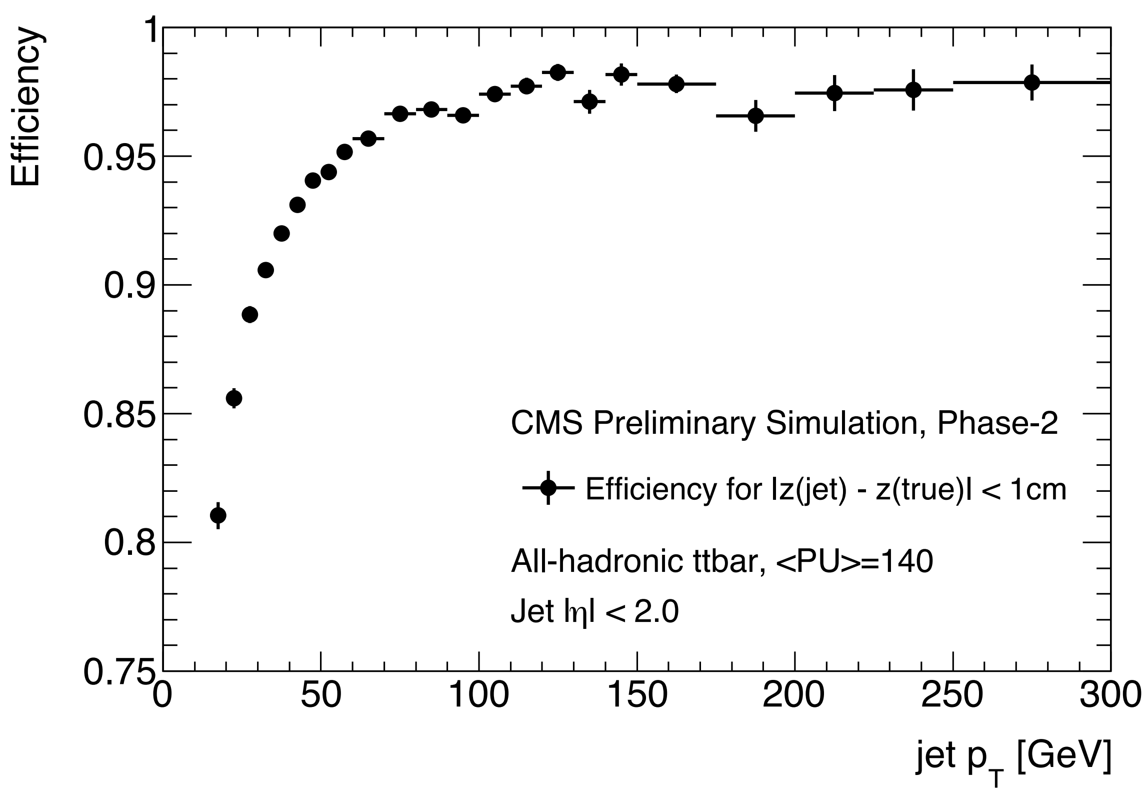


Using L1 Tracks: **Jets (CMS)**

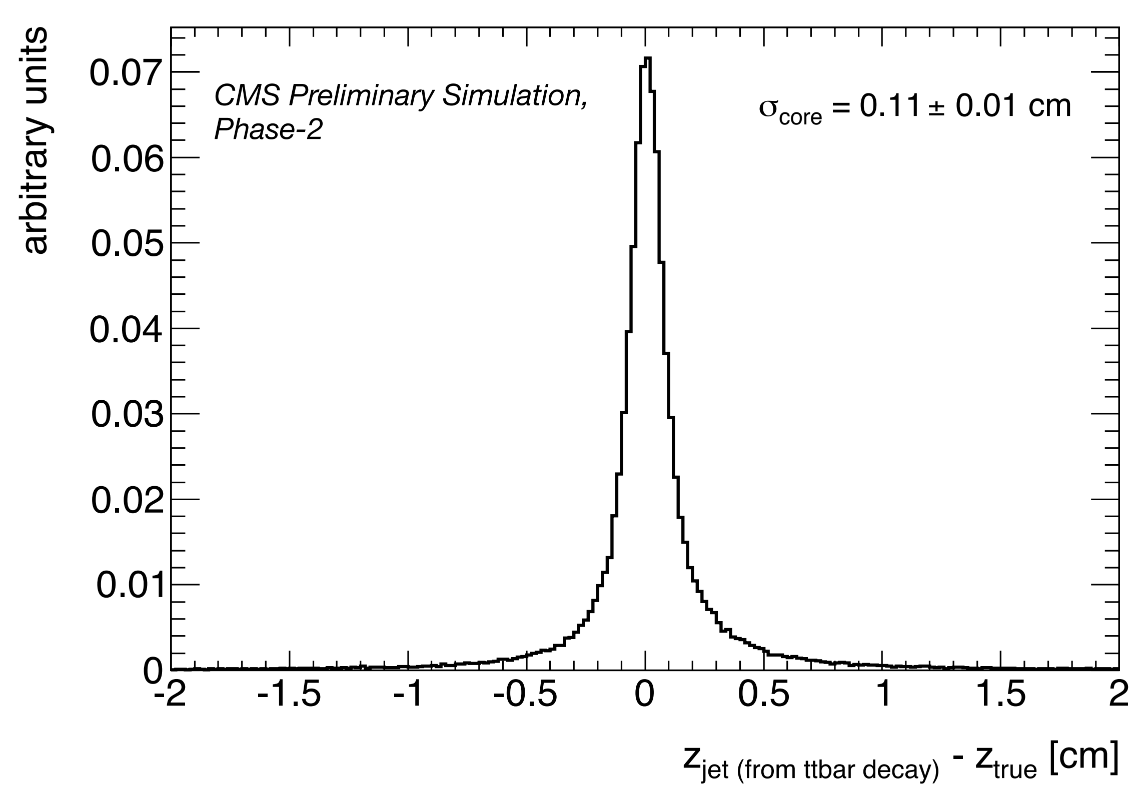
- Associate jets to nearby L1 tracks to measure jet's z position
- Define hadronic triggers requiring jet vertex consistency
  - Multijet triggers
  - H_T (missing H_T) triggers, $H_T = \Sigma(\text{jet } p_T)$



High efficiency to measure jet z position

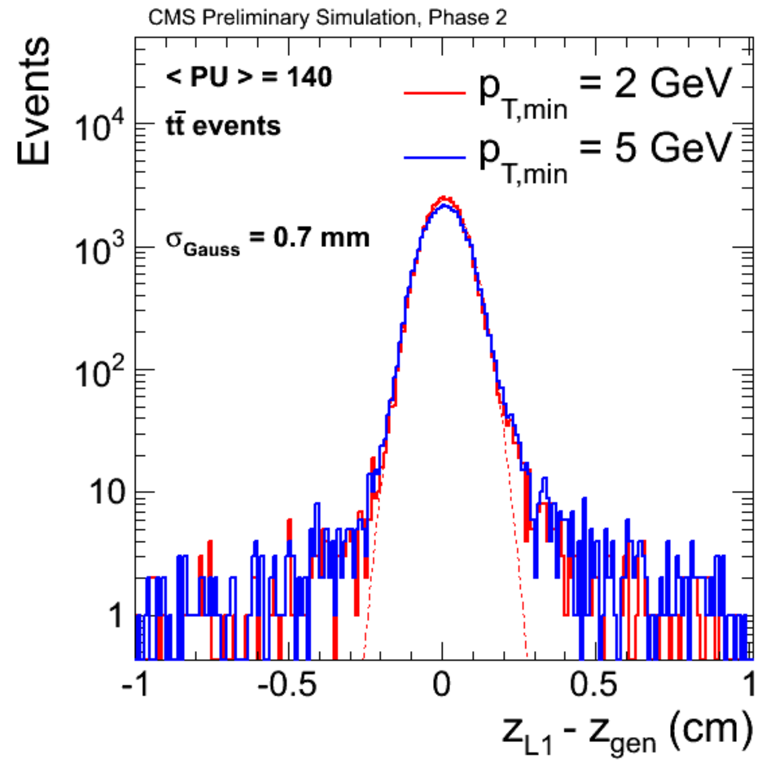


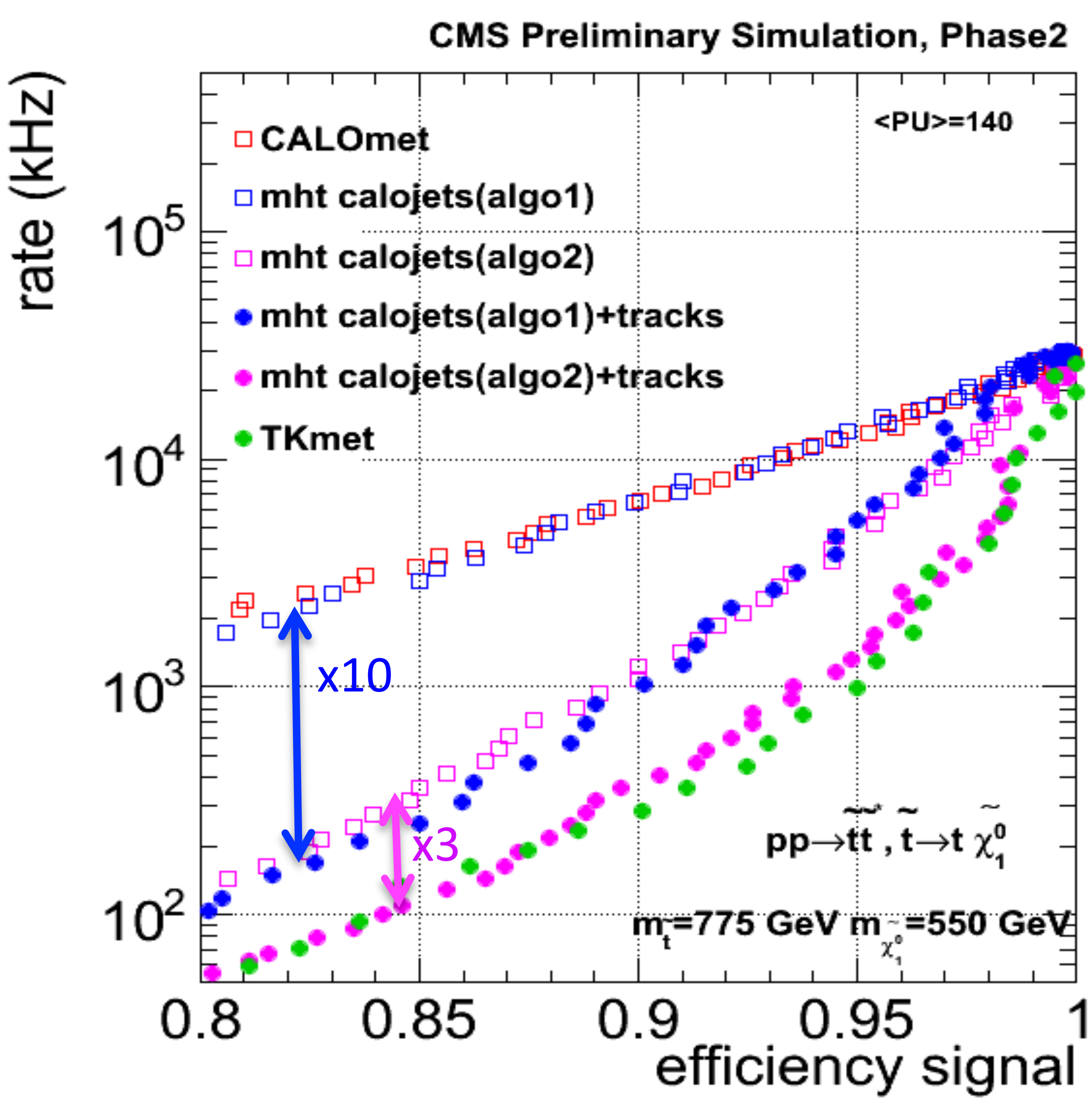
~1mm z resolution (all-hadronic ttbar)



Using L1 Tracks: **Track MET (CMS)**

- Use L1 tracks to reconstruct primary vertex
  - <1mm resolution for high track multiplicity events
- Define "track MET" using L1 tracks from primary vertex





- Rate reductions for SUSY signal
  - Stop pair production with hadronic top decays
  - Missing H_T with/without vertex association
    - *Two L1 calorimeter jet algorithms, different PU subtraction methods*
  - Sizable rate reductions!

Conclusions

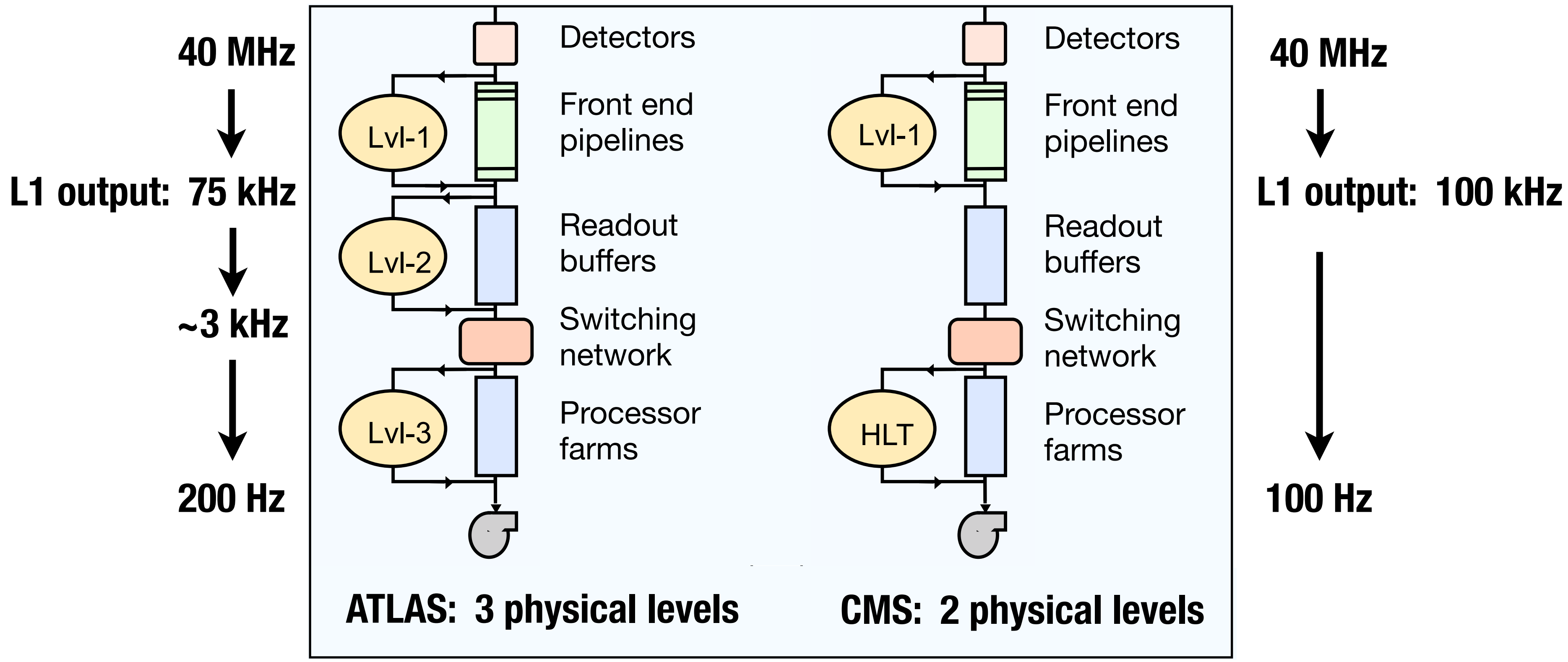
- HL-LHC
  - High instantaneous luminosity with ~3000 fb^{-1} collected over 10 year period
  - Challenging environment for the experiments with <PU>=140
- Maintaining high efficiencies while keeping event rates under control requires tracking @ L1 trigger
  - Single e/μ rates can be reduced by factor of O(10)
  - Powerful also for hadronic triggers
- Different approaches to L1 tracking studied
  - Region-of-interest seeded (ATLAS)
  - Self-seeded track trigger (CMS)

- **Incorporating tracking information in L1 trigger important to achieve necessary rate reductions as driven by the physics!**

BACKUP

ATLAS & CMS: **Trigger System**

- Current trigger systems
    - **L1 trigger**
        - *Hardware-based, implemented in custom-built electronics*
        - *Muon & calorimeter information with reduced granularity, no tracking information*
    - **High-Level Trigger (HLT)**
        - *Software-based, executed on large computing farms*
        - *Tracking information & full detector granularity*
        - *ATLAS use level-2 & event filter, CMS single-step HLT*



L1 trigger decision in ~2.5 (4) μs for ATLAS (CMS)

ATLAS & CMS: Phase-1/2 Upgrades

- **Phase-1 upgrades (2018-2019)**
  - **ATLAS**
    - *Fast Track Trigger (FTK) @ Level 1.5*
    - *New small muon wheel*
    - *Finer granularity in L1 calorimeter trigger*
  - **CMS**
    - *Upgraded L1 trigger system - improved high-PU performance*
    - *New pixel detector*
    - *Upgrade hadronic calorimeter (HCAL) electronics & photodetectors*
- **Phase-2 upgrades (2023-2025)**
  - **ATLAS / CMS**
    - *All new tracker detector (ATLAS, CMS)*
    - *Triggering @ L1 (ATLAS, CMS)*
    - *Upgrade muon/calorimeter electronics (ATLAS)*
    - *Upgraded endcap calorimeters (CMS)*
    - *Upgrade barrel calorimeter front-end electronics (CMS)*