The ATLAS Electron and Photon Trigger Performance in Run-2

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on behalf of the ATLAS collaboration

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ATLAS EXPERIMENT

UNIVERSITY OF SUSSEX

Overview

Introduction

The ATLAS trigger system in a nutshell, Ringer algorithm
offline electron and photon reconstruction

electron and photon trigger efficiency measurements

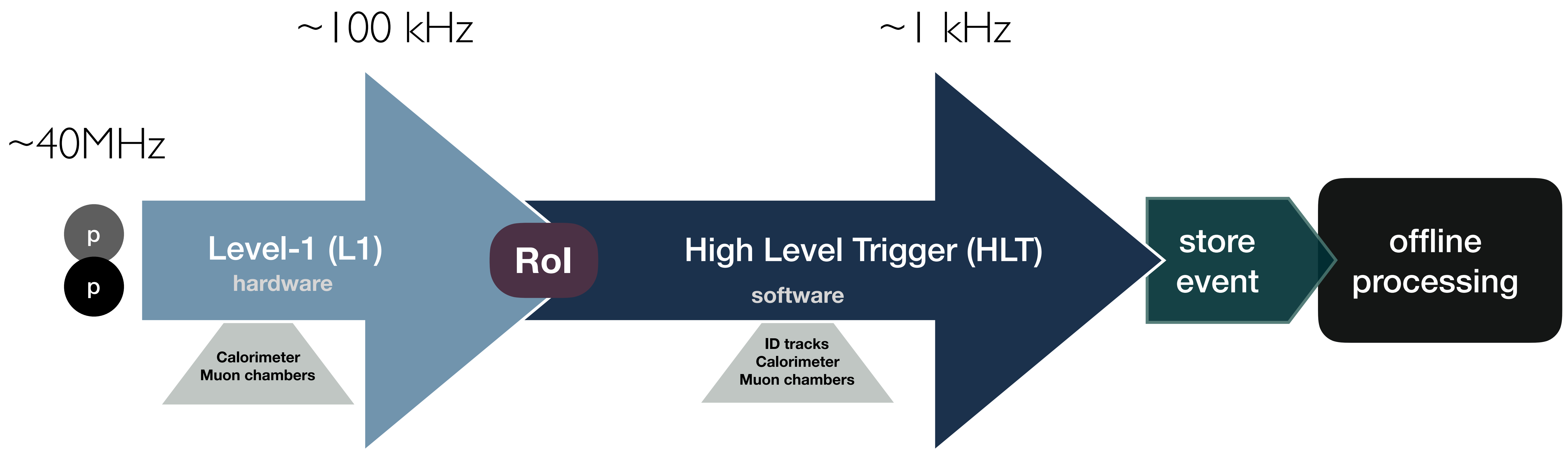
Z tag-and-probe method, Z radiative decay method, Bootstrap method

Performance of electron and photon triggers during Run-2

Level-1 performance, electron and photon trigger evolution,
trigger in heavy ion collisions

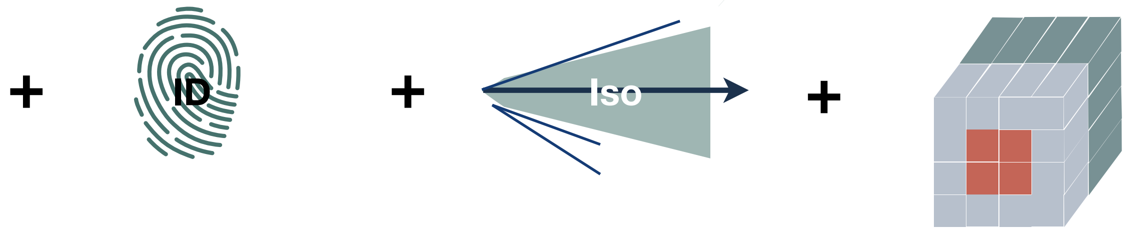
Conclusions and Outlook

The ATLAS trigger system in a nutshell



2g20	tight	icalovloose	L1_2EM15VHI
e26	lhtight_nod0	ivarloose	L1_EM22VHI

energy threshold and multiplicity +



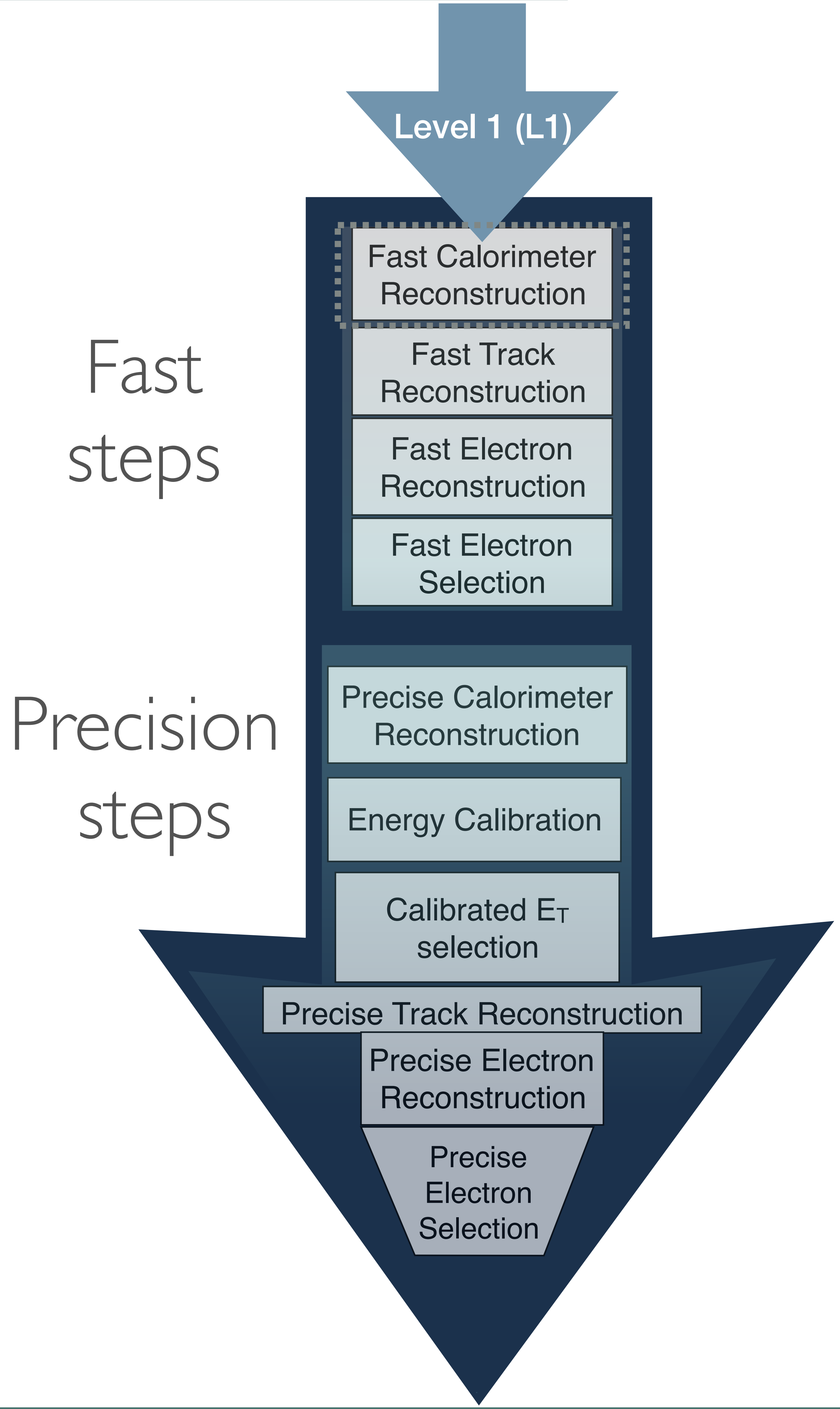
Level-1

2x2 trigger tower cluster as RoI in EM calorimeter

V: varying E_T threshold within -2 and +3 GeV of nominal threshold

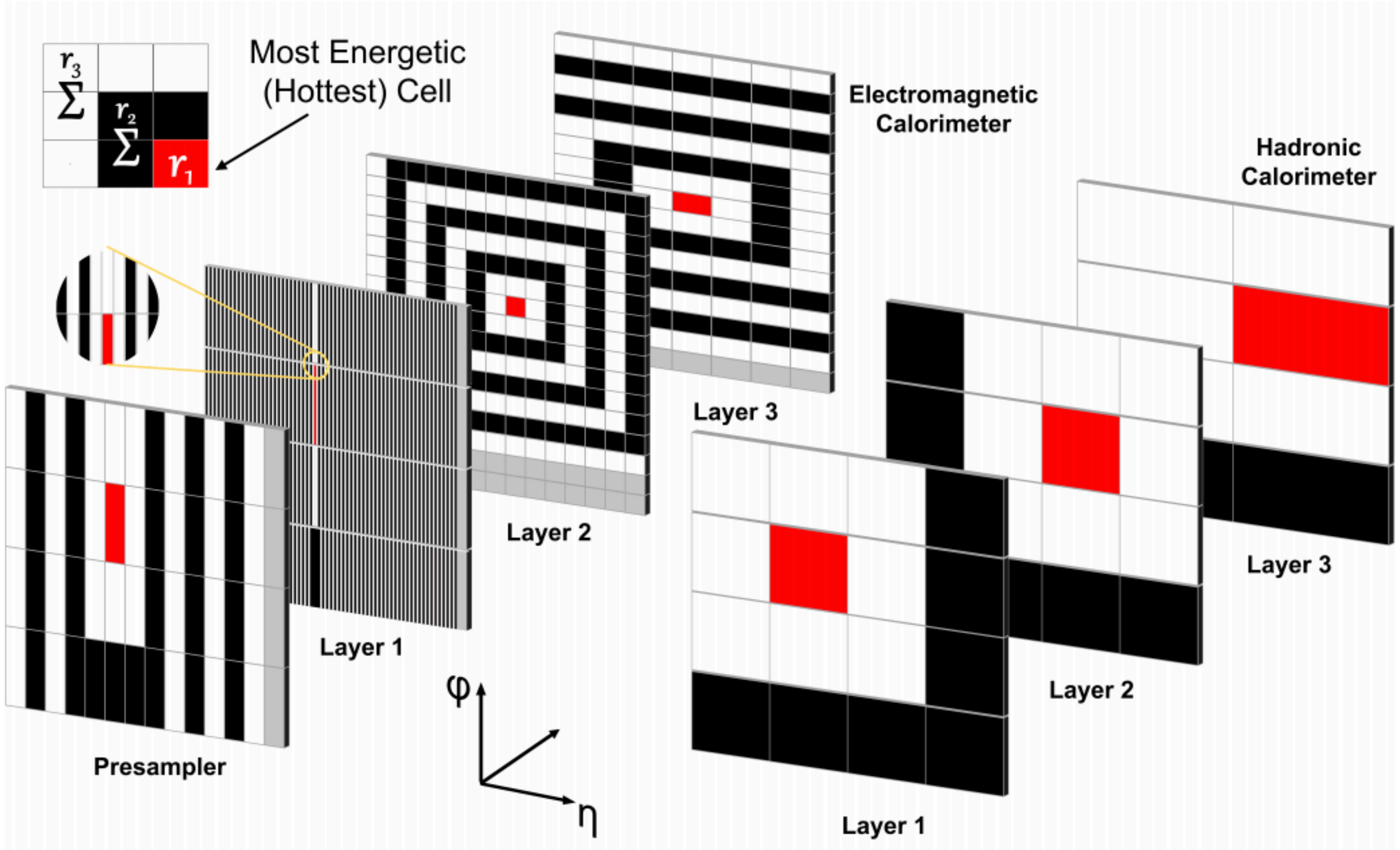
H: veto on hadronic leakage

I: E_T dependent isolation of cluster in EM calorimeter



Ringer algorithm

- used from 2017 on to trigger electrons (Fast Calorimeter step) with $E_T > 15$ GeV
- use lateral shower development
- concentric ring energy sums in each calorimeter layer
- transverse energy in each ring normalised to total transverse energy in the RoI
- ring energies fed into multilayer perceptron (MLP) neutral networks



Ringer increases Fast Calorimeter step reconstruction time, but reduces input candidates to the tracking
→ significantly reduced CPU demand
(50% CPU reduction for the lowest p_T unprescaled single electron trigger)

‘Offline’ electron and photon reconstruction and identification

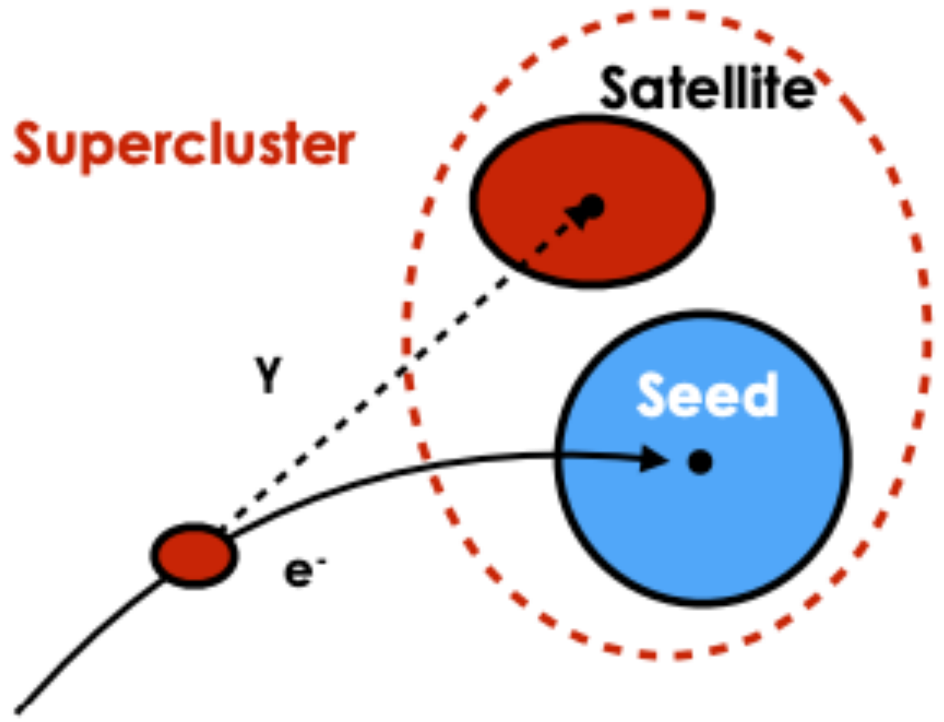
Electrons

- Identification based on a likelihood discriminator
- ‘*loose*’ , ‘*medium*’, ‘*tight*' working points considered
- using GSF (Gaussian-Sum Filter) as a generalisation of the Kalman fitter, better account for energy loss in Inner Detector

Photons

- identification based on calorimetric variables
- two identification working points, ‘*loose*' and ‘*tight*’
- ‘*loose*' relying on shower shapes in the second electromagnetic calorimeter layer and hadronic deposits
- ‘tight’ including first layer of electromagnetic calorimeter

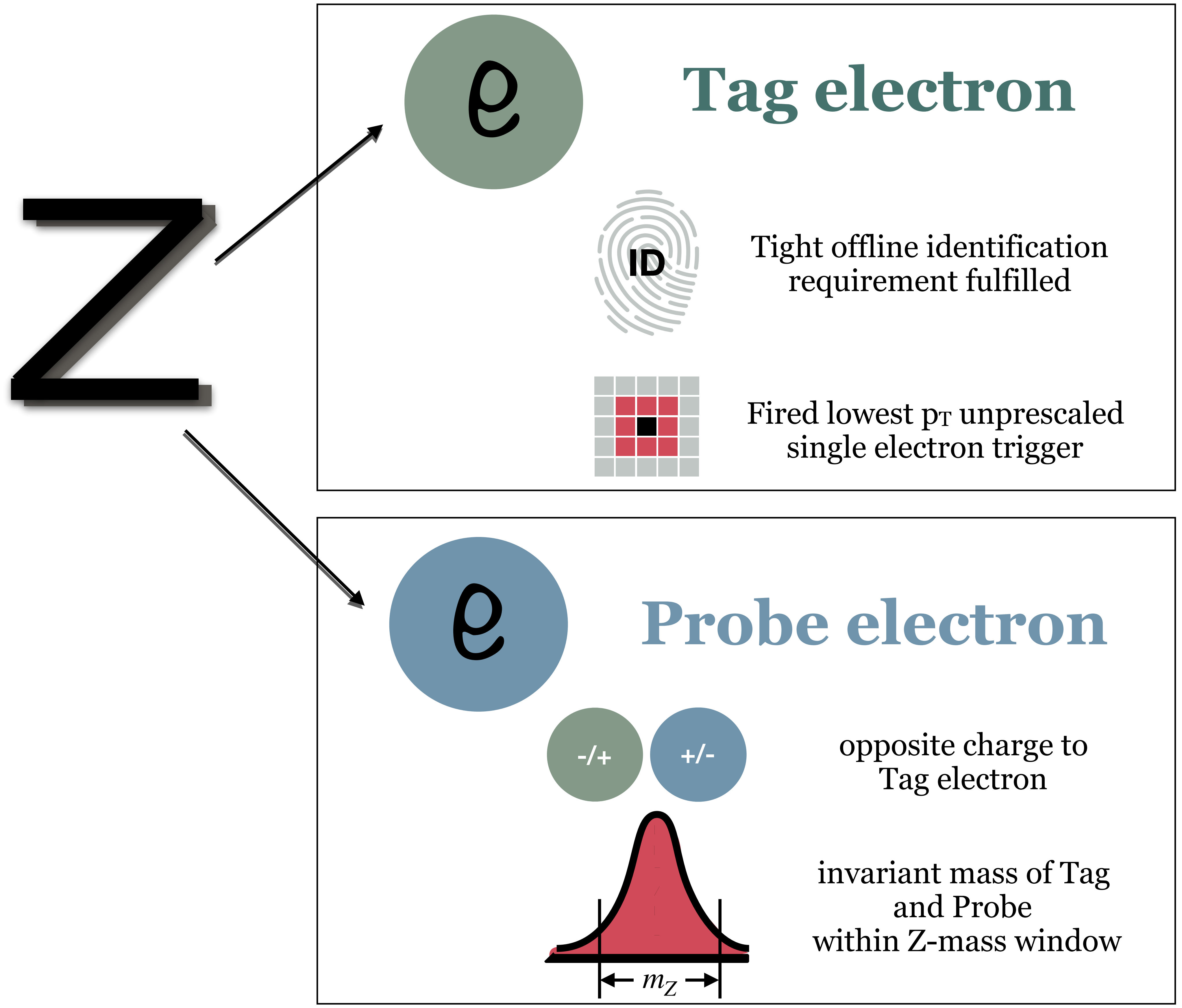
using Supercluster to improve electron and photon energy reconstruction in cases with Bremsstrahlung or pair production



[1]

Performance measurement techniques - electrons

Z tag-and-probe method



$$\epsilon_{\text{total}} = \epsilon_{\text{offline}} \times \epsilon_{\text{trig}} = \left(\frac{N_{\text{offline}}}{N_{\text{all}}}\right) \times \left(\frac{N_{\text{trig}}}{N_{\text{offline}}}\right)$$

compute trigger efficiency
with respect to offline electron definitions

systematic uncertainties

- given by varying tag definition, Z-mass window and background subtraction method
- central value is average of variations

Performance measurement techniques - photons

Z

Tag electrons/muons

e/μ e/μ

Fired lowest p_T unprescaled single and double electron/muon trigger

-/+ +/-

opposite charge, same flavour lepton pair

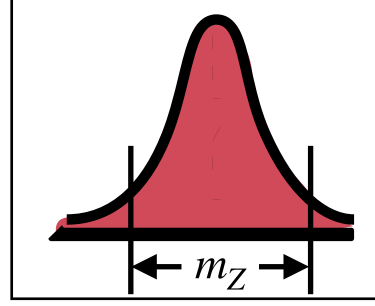
ID

medium offline identification requirement fulfilled, FCLoose isolation

Probe photon

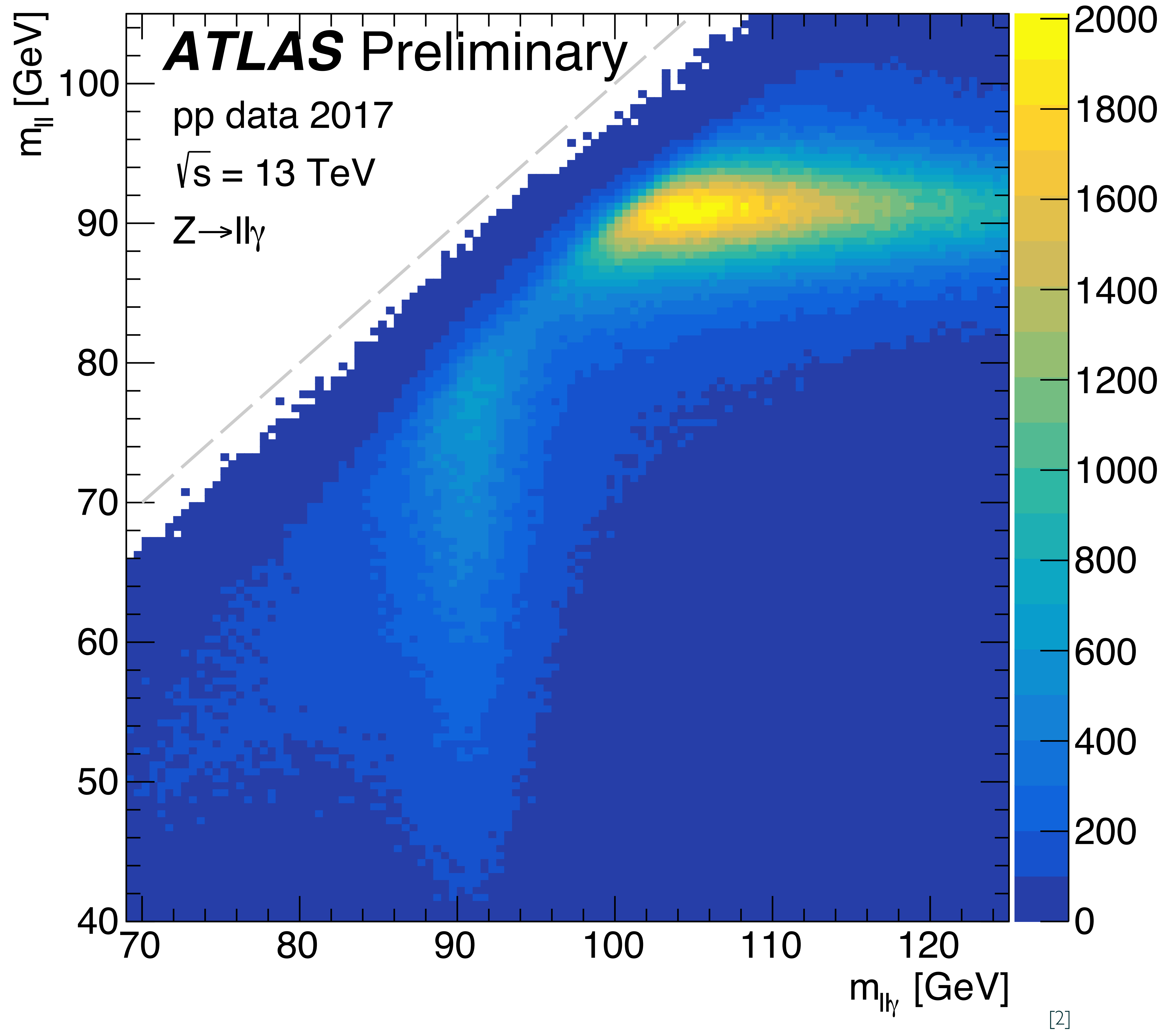
ID

tight photon candidate
η < |2.37| E_T > 10 GeV
satisfy isolation of interest



cut on $m_{\ell\ell}$ and $m_{\ell\ell\gamma}$
to avoid ISR photons

Z radiative decay method



[2]

Performance measurement techniques - photons

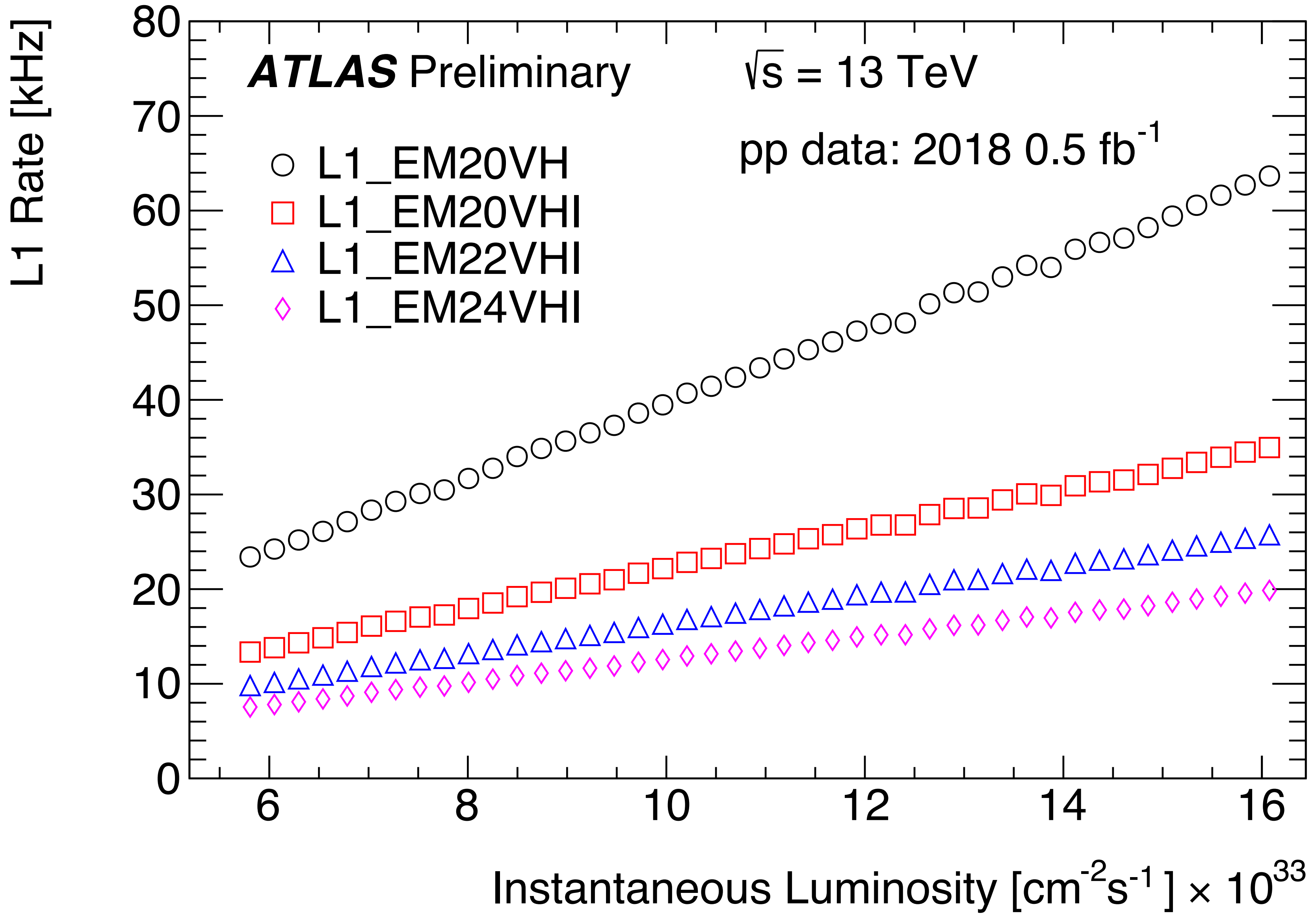
Bootstrap method

$$\epsilon^{\gamma}_{trig} = \epsilon_{HLT|BS} \times \epsilon_{BS}$$

ϵ^{γ}_{trig}	$\epsilon_{HLT\|BS}$	ϵ_{BS}
High Level Trigger efficiency with respect to offline selection	**High Level Trigger efficiency on bootstrap sample**	**Bootstrap sample efficiency with respect to offline selection**
	based on Level-1 - only triggers or loose and low E_T photon triggers	computed on events selected by special 'random' trigger

- large, uncontrolled background contamination (main source of uncertainty)
- systematic uncertainty as difference between data and simulated $H \rightarrow \gamma\gamma$ events

Level-1 trigger performance



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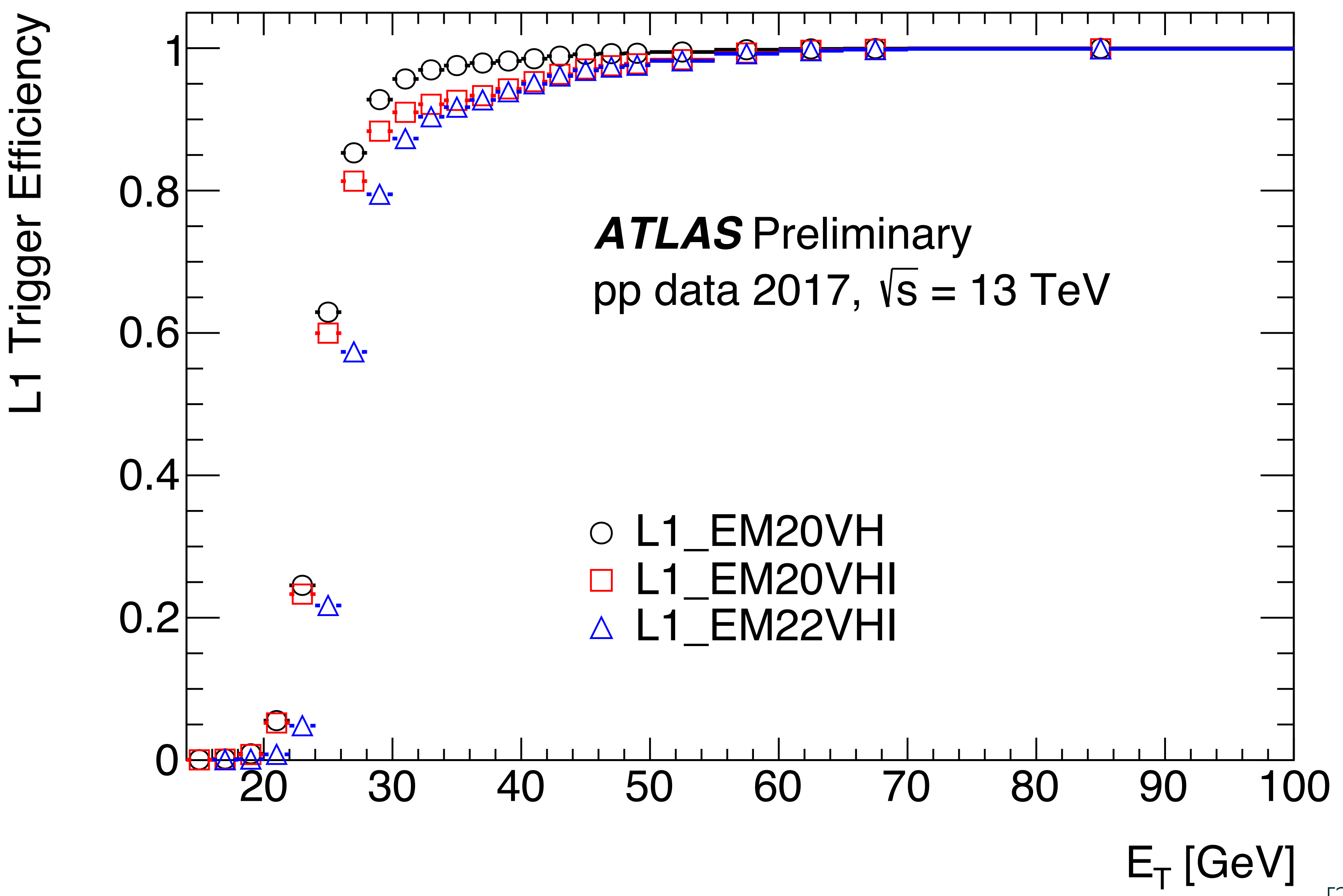
- linear increase of rate with instantaneous luminosity
- single Level-1 EM triggers: raise of threshold by 2 GeV leads to 25% decrease in rate

rate reduction of ~44% per leg by including electromagnetic calorimeter isolation at Level-1, efficiency decrease up to 5%



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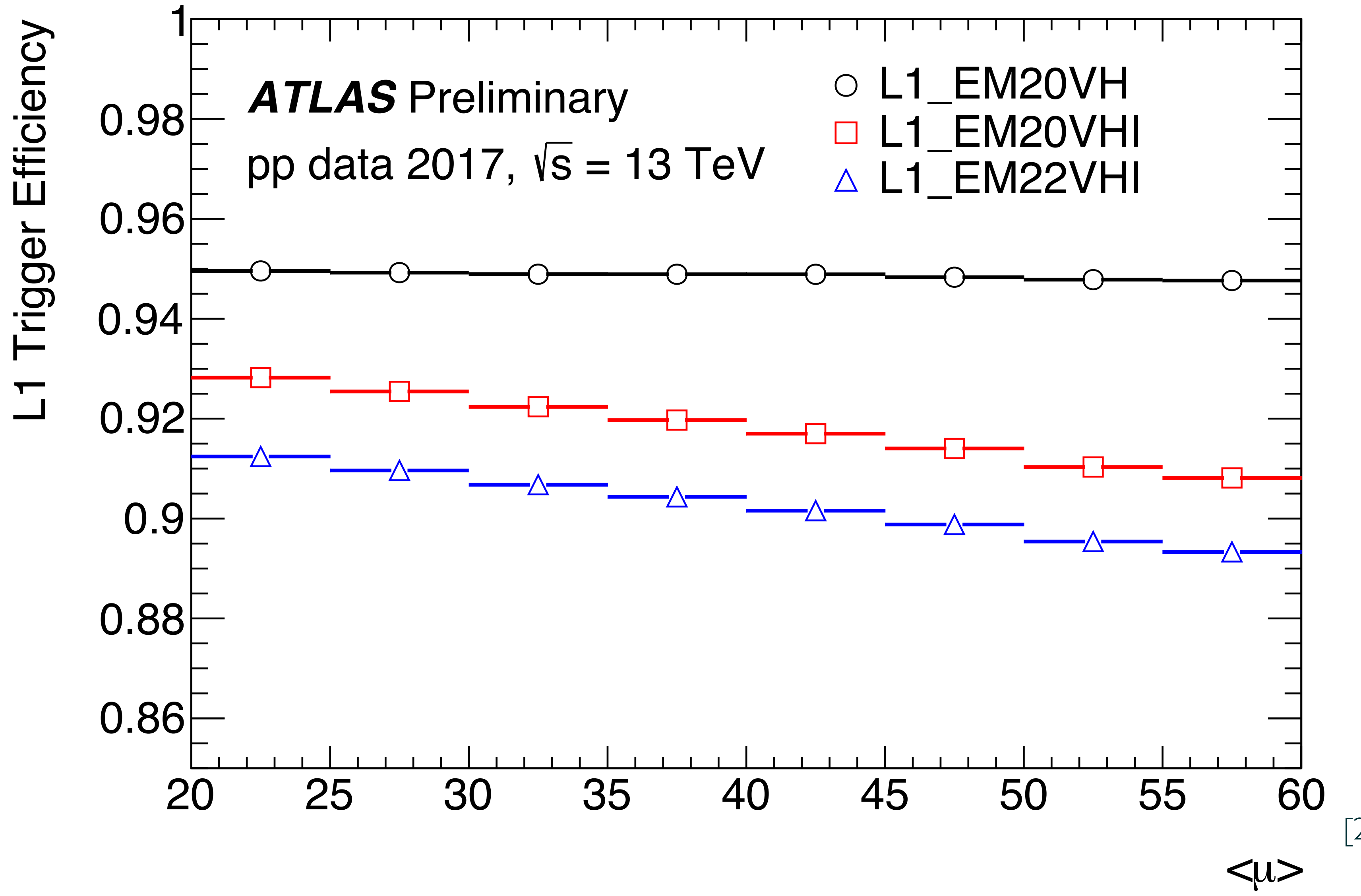

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Photon trigger evolution and performance

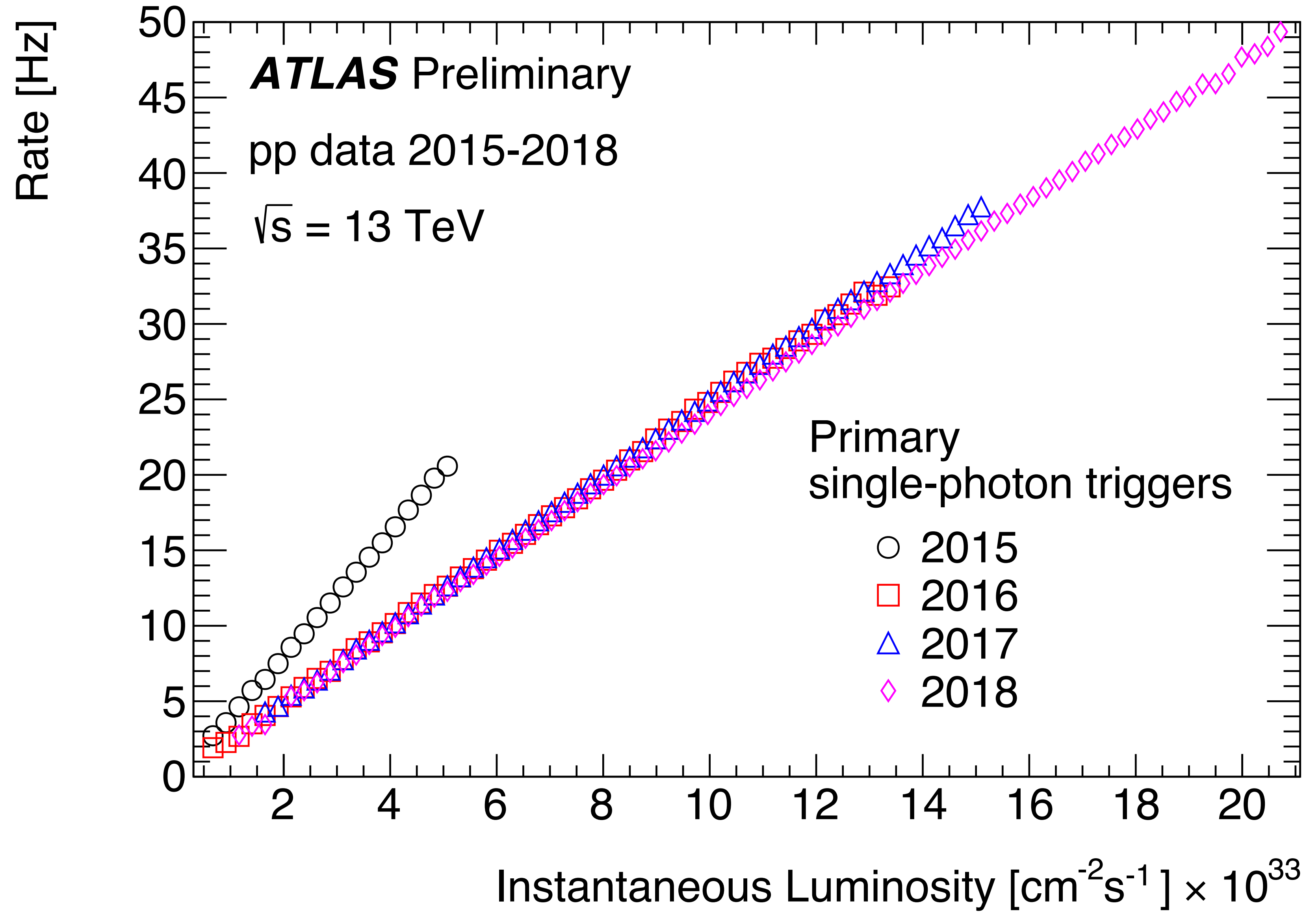
	2015	2016	2017	2018
Single photon	g120_loose	g140_loose		
primary diphoton	g35_loose_g25_loose		g35_medium_g25_medium	
tight diphoton	2g20_tight	2g22_tight	2g20_tight_icalovloose	

→ BSM physics, high E_T photons

→ Higgs to diphoton

→ low mass diphoton searches

reoptimisation of 'tight' photon selection at the end of 2017



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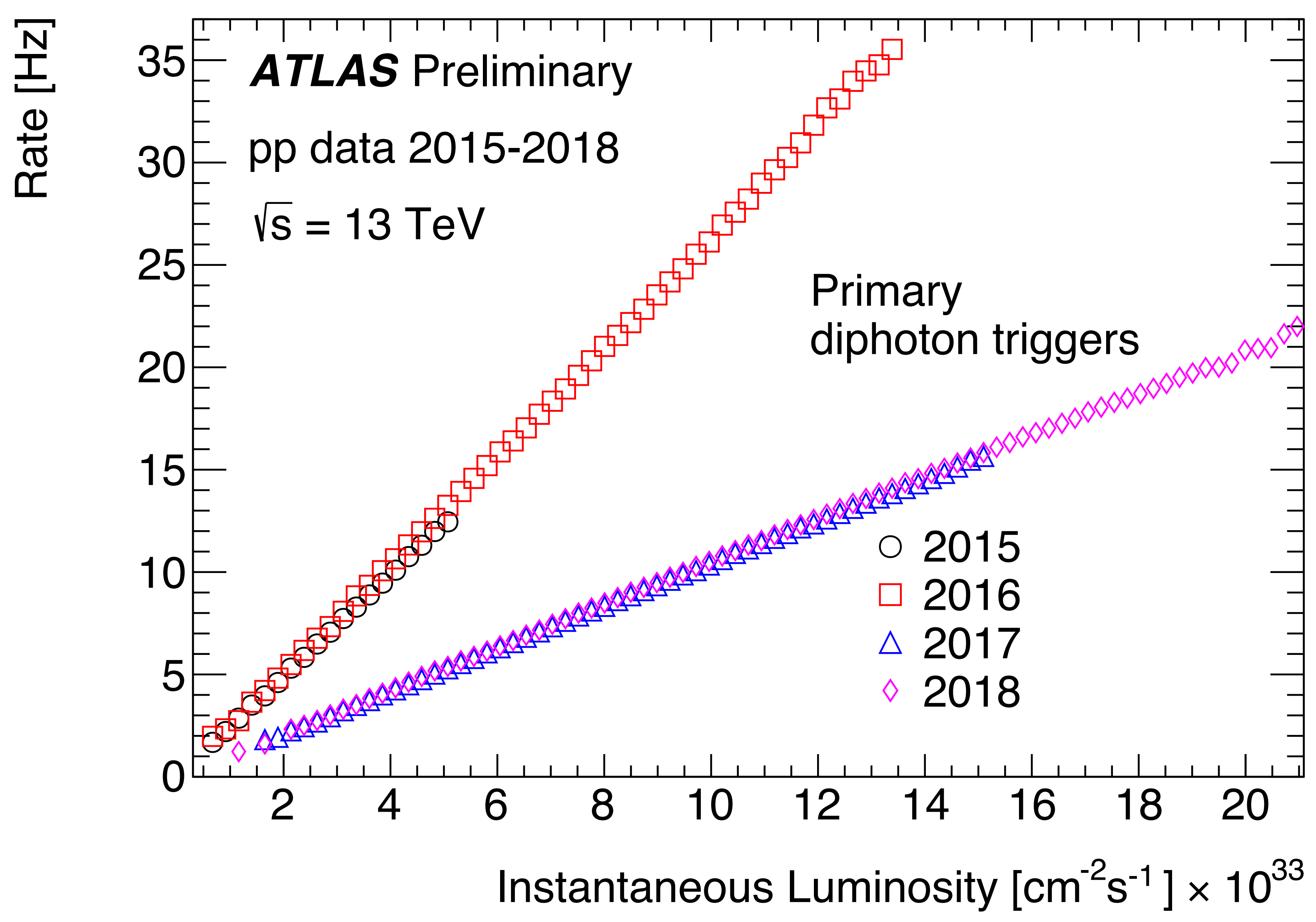

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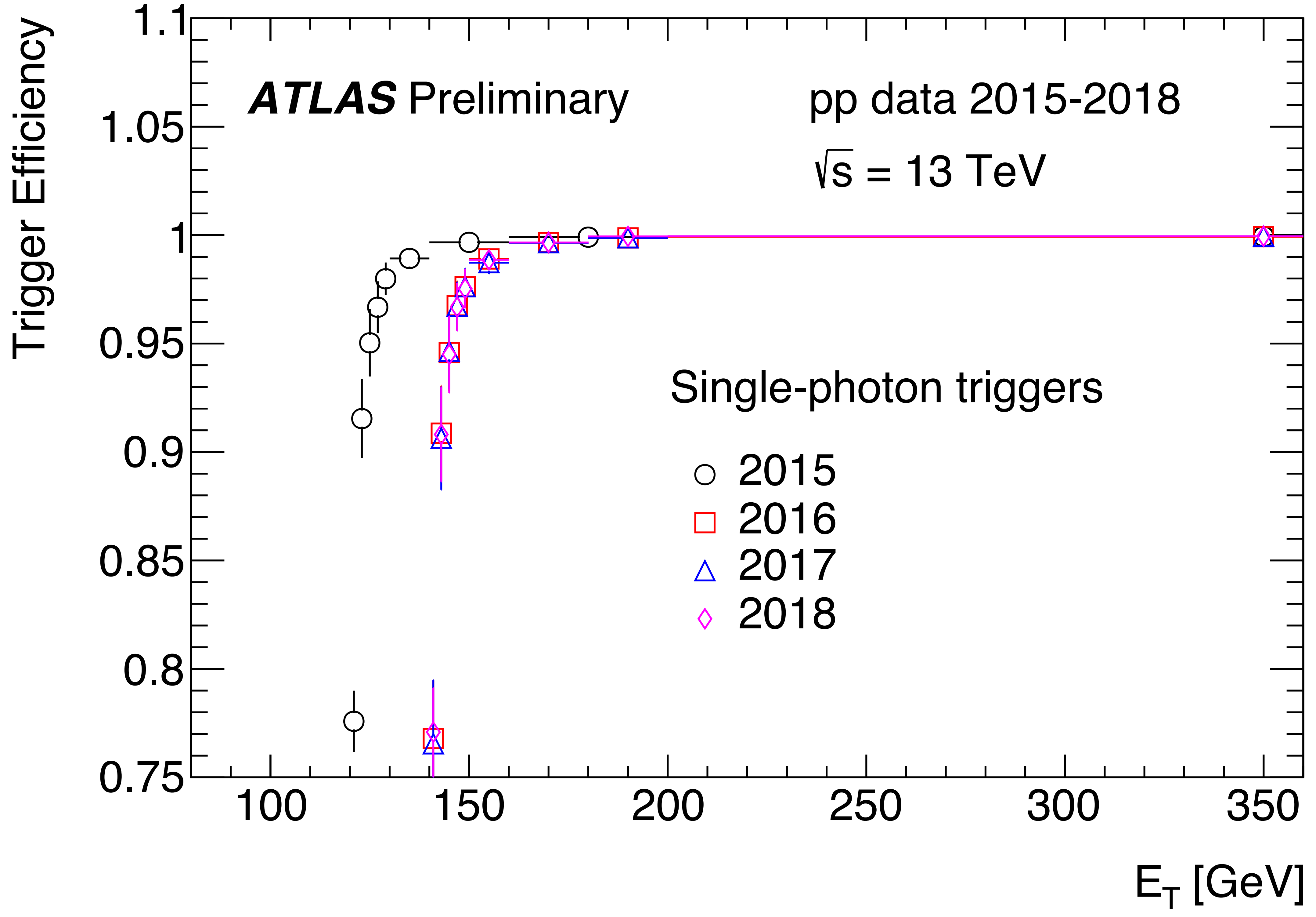
Photon trigger evolution and performance



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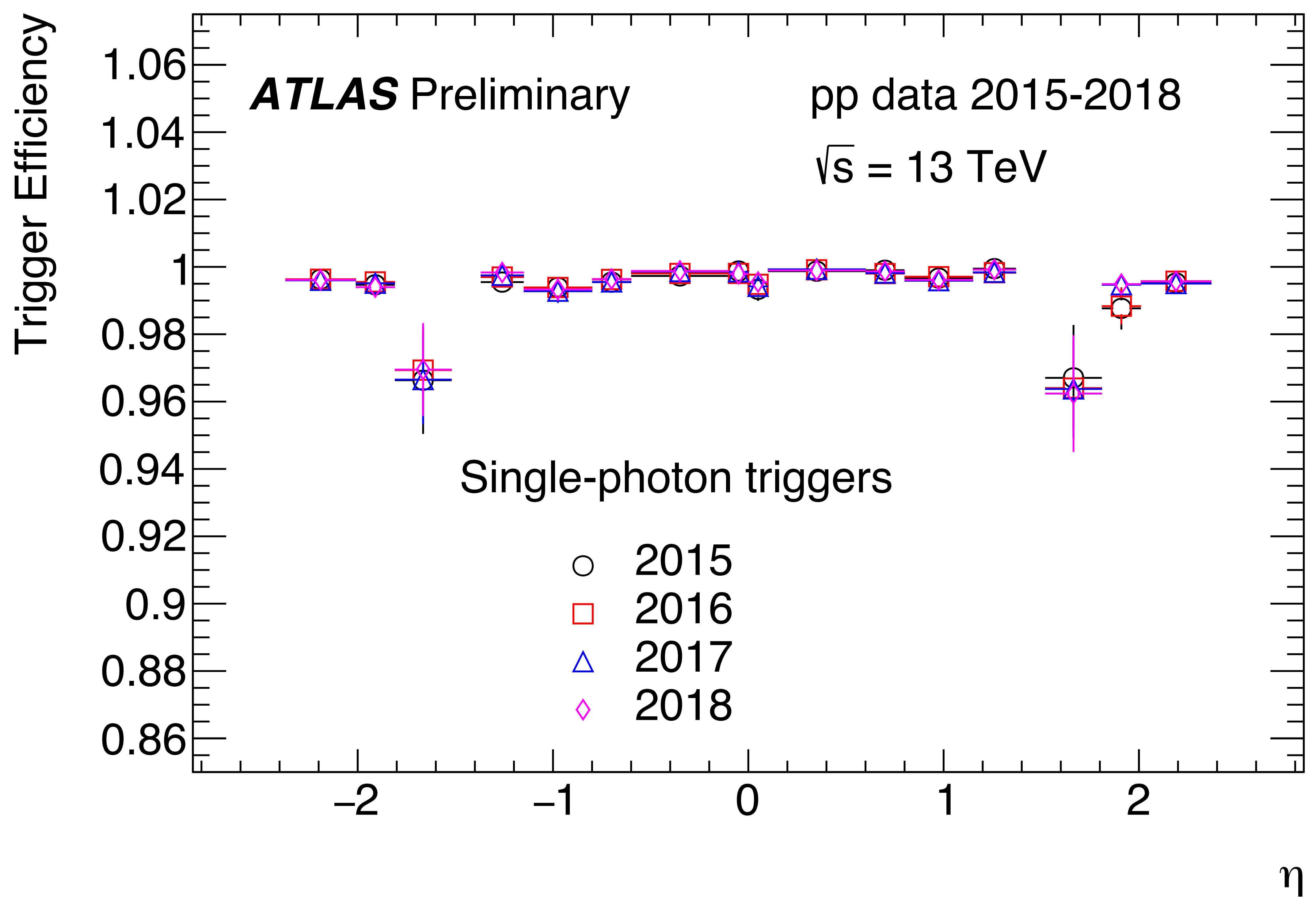

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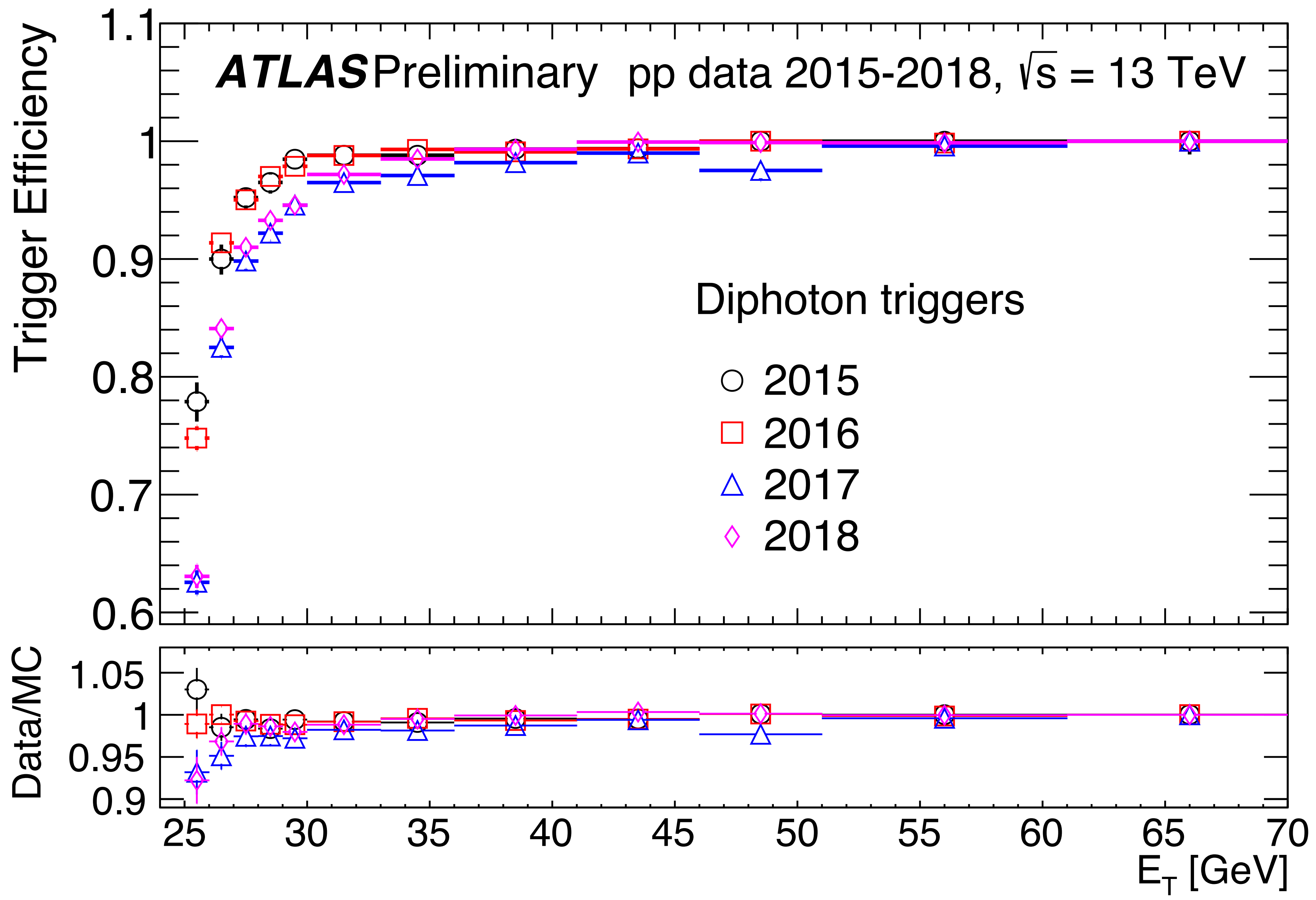
- bootstrap method used to calculate the efficiency
- total uncertainties dominated by systematics, in total O(1%)
- efficiency in 2016 rises faster due to lower pile-up conditions

Photon trigger evolution and performance



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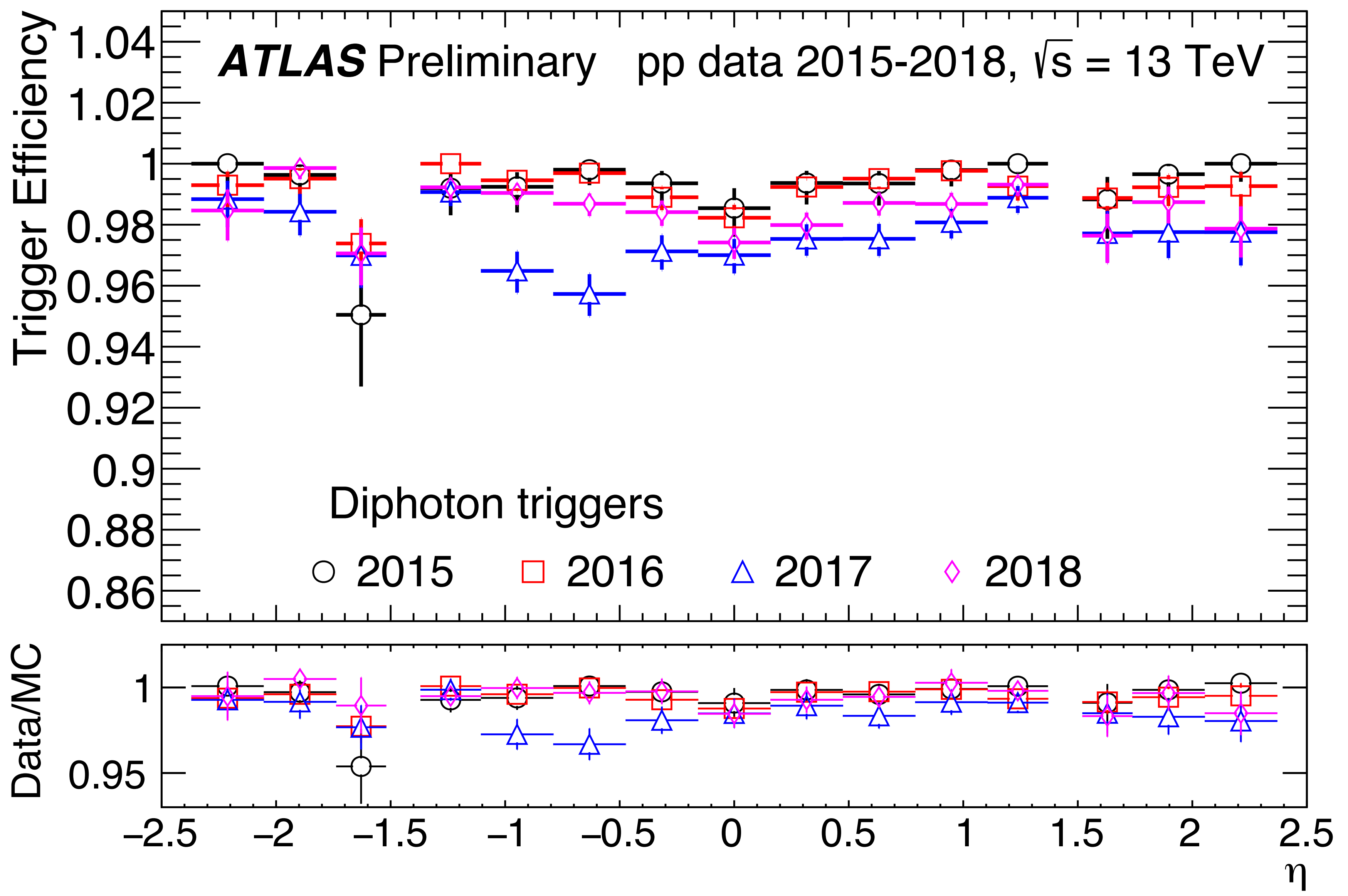

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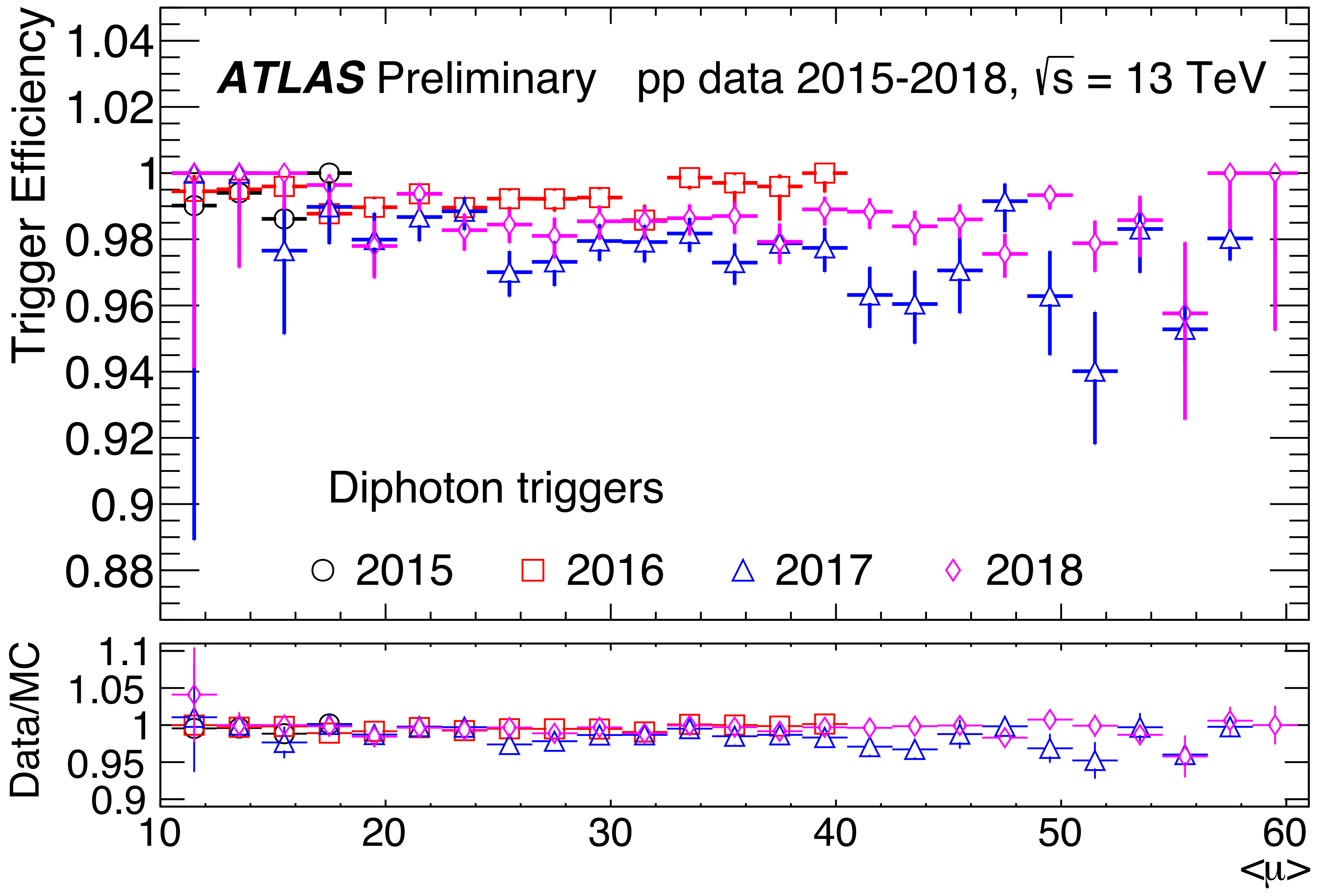
- efficiency measured with radiative Z decay method
- lower efficiency in 2017-2018 due to **medium** instead of **loose** online ID
- no pseudorapidity or pile-up dependency in efficiency



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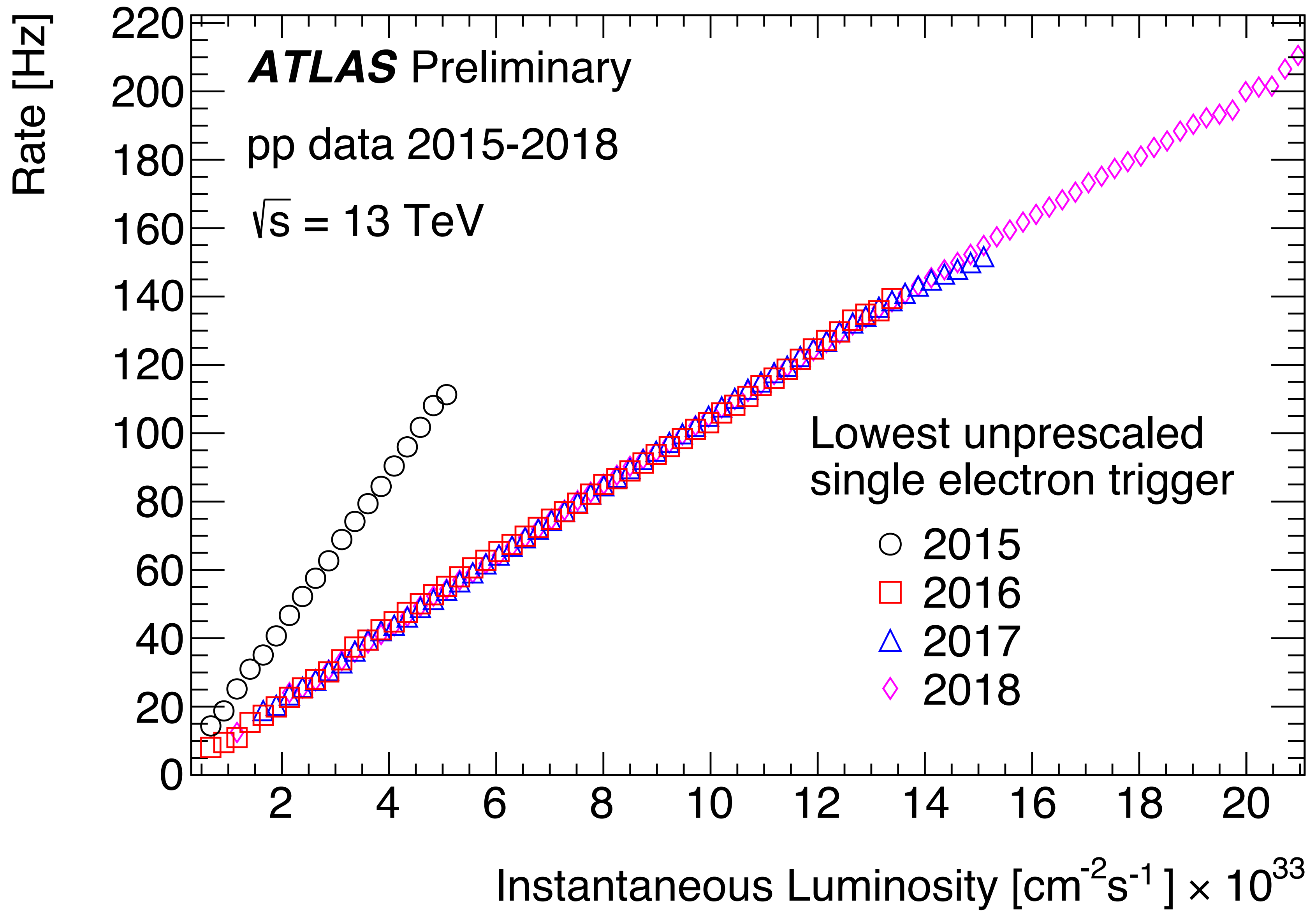
Electron trigger evolution and performance

	2015	2016	2017-2018
Single electron	e24_lhmedium (EM20VH) e120_lhloose e200_etcut	e26_lhtight_nod0_ivarloose (EM22VHI) e60_lhmedium_nod0 e140_lhloose_nod0 e300_etcut	
dielectron	2e12_lhloose (2EM10VH)	2e17_lhvloose_nod0 (2EM15VH)	2e17_lhvloose_nod0 (2EM15VHI) 2e24_lhvloose_nod0 (2EM20VH)



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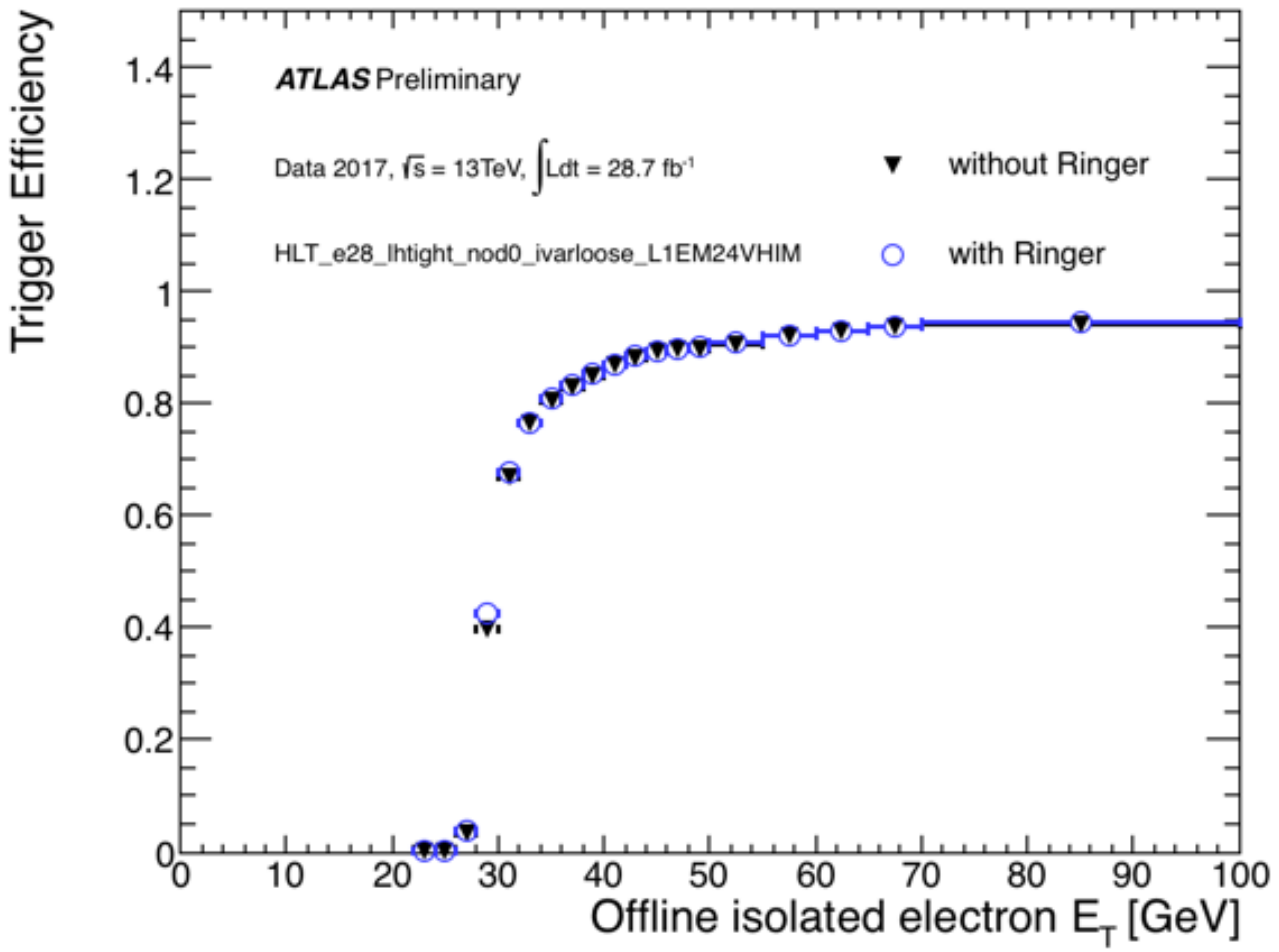
Performance of the Ringer algorithm



[3]

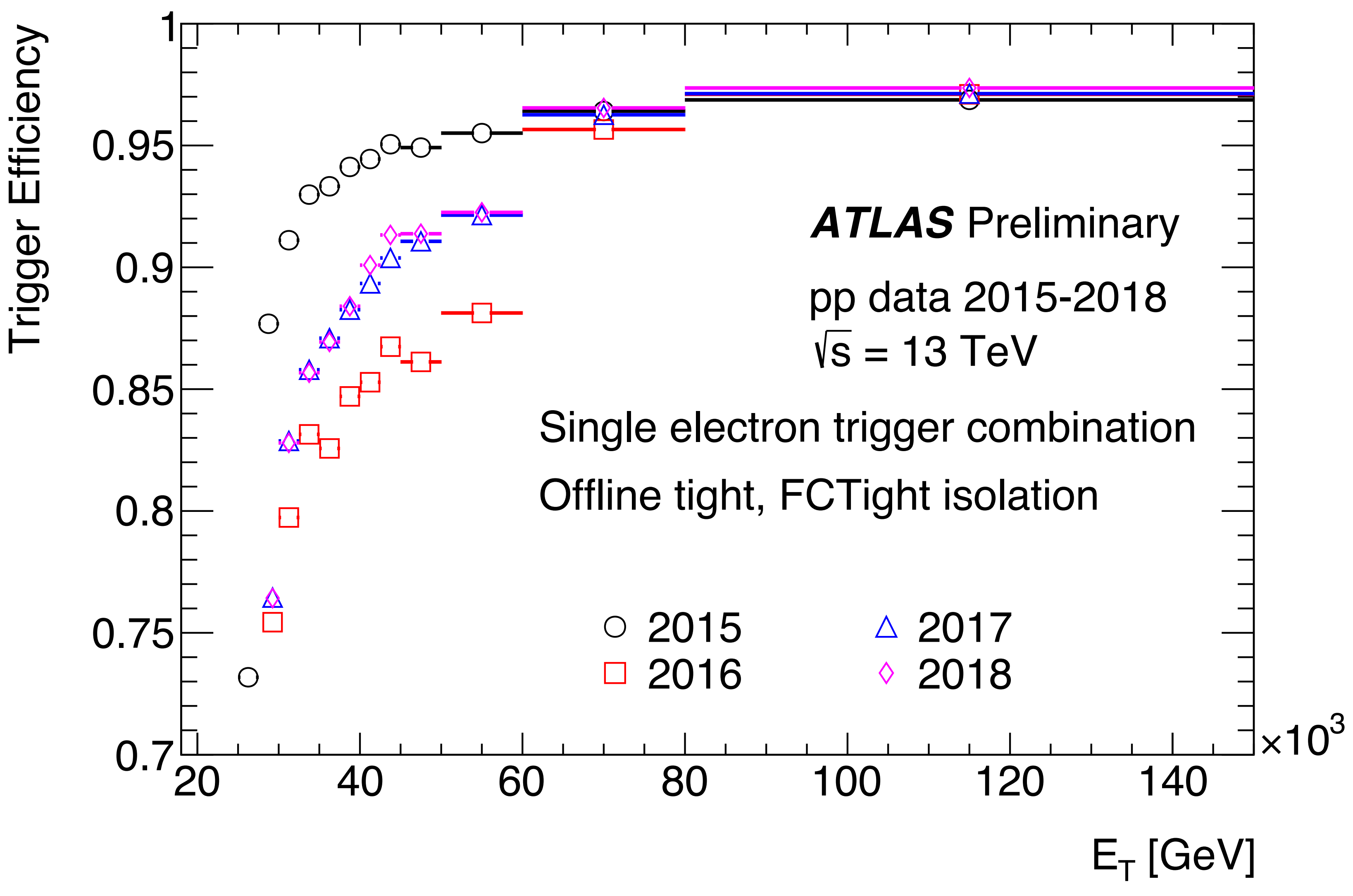
evaluation of Ringer performance in 2017

Comparing Ringer and cut-based selection at fast reconstruction

nearly unchanged efficiency behaviour in single electron case

50% CPU reduction for the lowest p_T unprescaled single electron trigger

Performance evolution of single electron trigger



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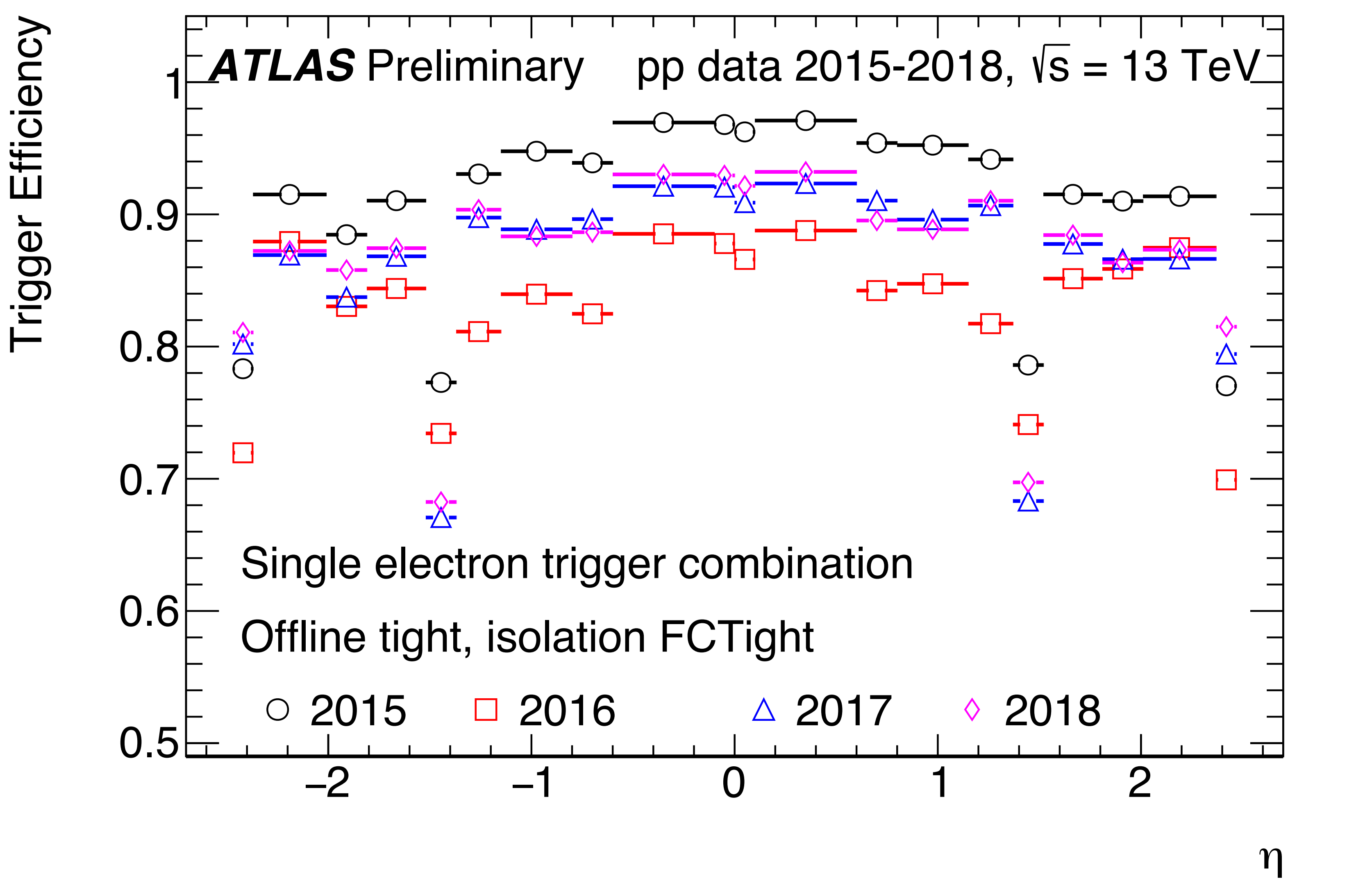

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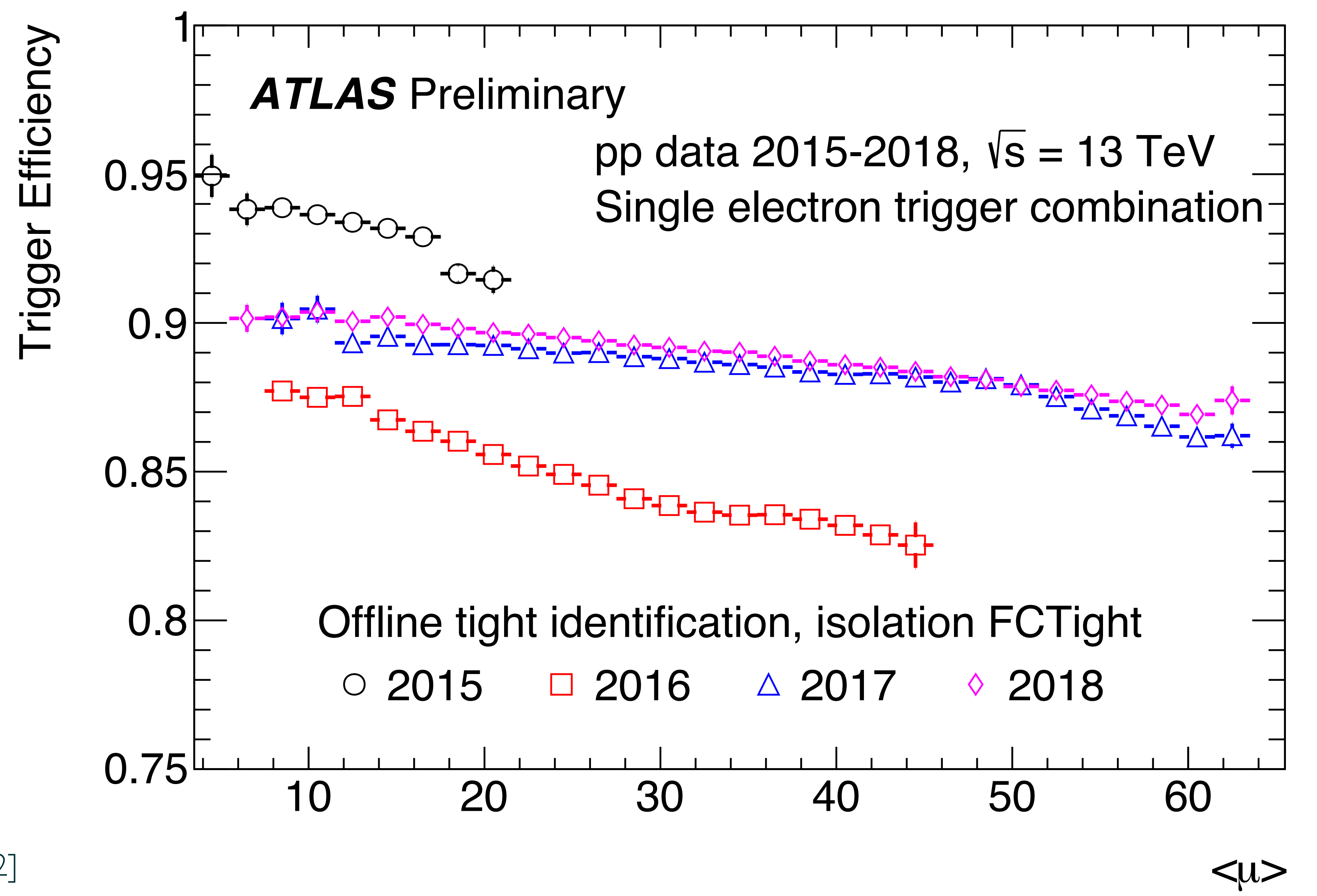


[2]

sharper turn on in 2015

lower E_T threshold, no isolation, looser identification

inefficiencies in 2016 below 60 GeV observed

due to LH calorimeter only selection in precision calorimeter step

2017 data driven likelihood selection, introduction of Ringer algorithm

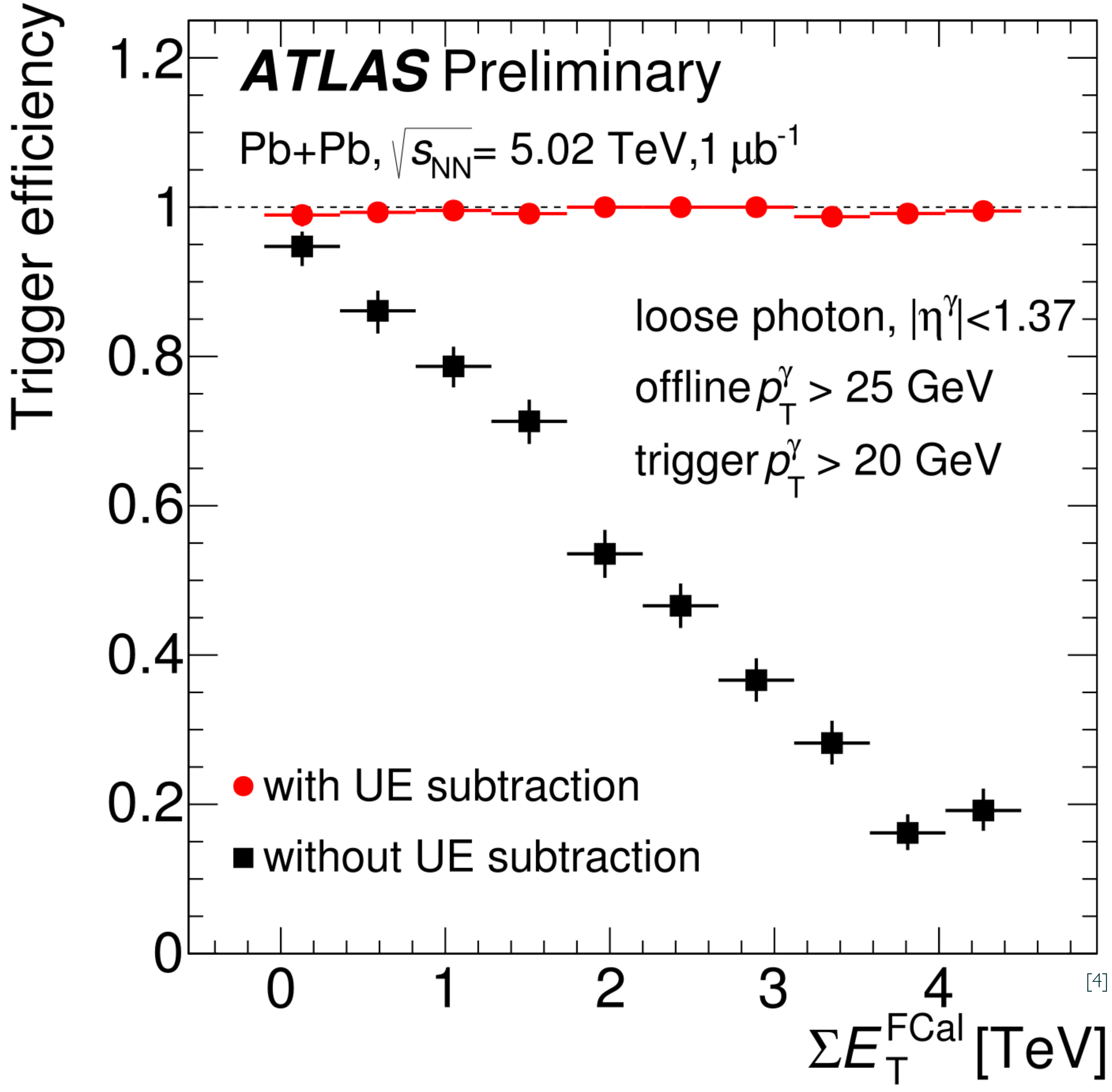
pile-up dependency reduced towards end of Run-2

residual dependency due to isolation requirements

photon trigger in heavy ion data taking

photons

- photon trigger efficiency evaluated with respect to offline-reconstructed photons
- efficiency shown with and without subtraction of the underlying event



[4]

Conclusion and Outlook

Good understanding of the electron and photon trigger performance during Run-2

established methods to measure trigger efficiencies, several improvements during Run-2 to adapt to changing conditions

Many ongoing efforts to improve the electron and photon trigger performance and CPU usage in Run-3

Aim to get closer to offline selections than in Run-2

moving towards multi-threading on trigger level

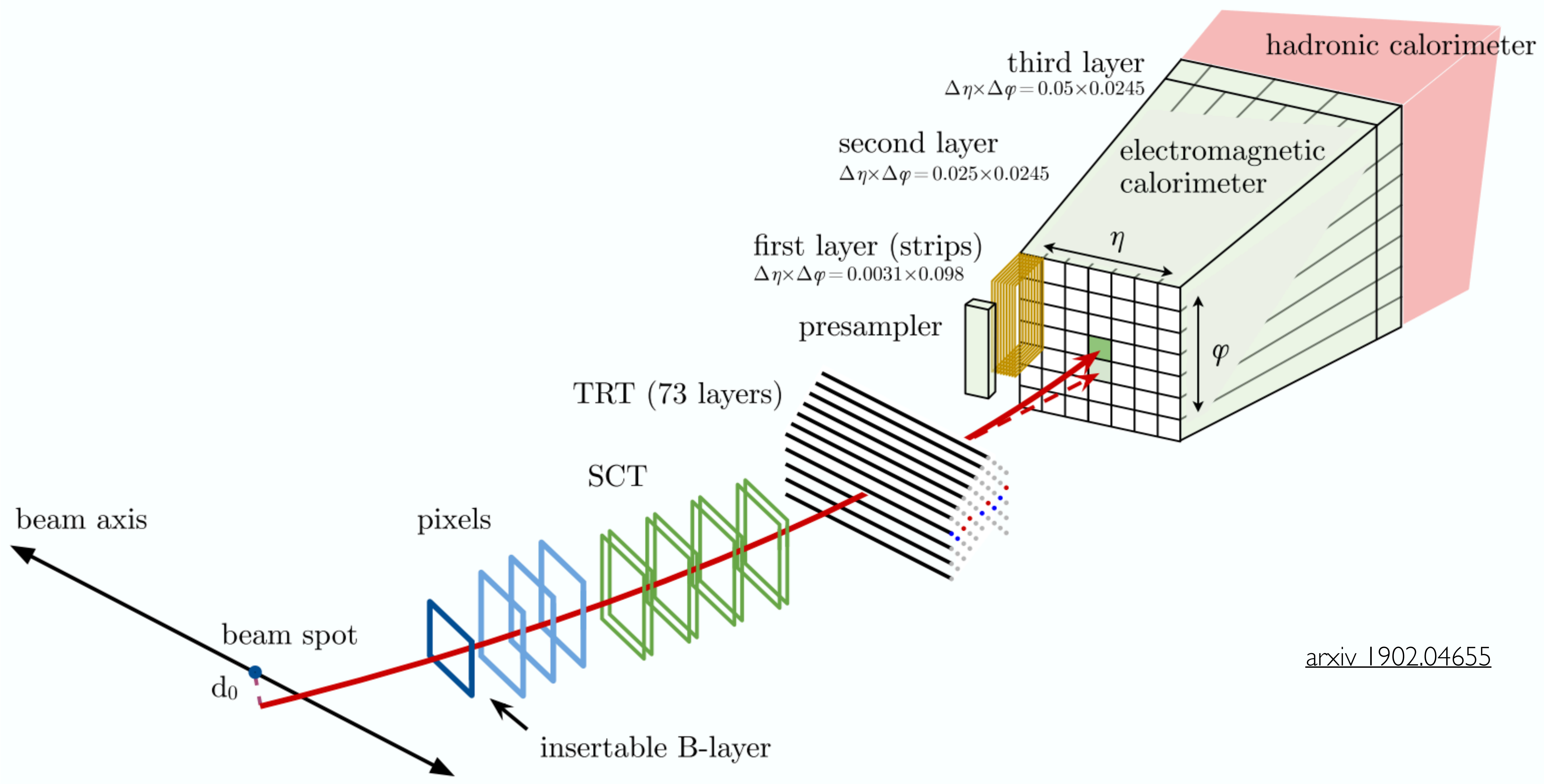
update of Level-1 Calo electronics with improved granularity, will lead to improved background rejection and better efficiencies

References

[1] 'Electron and photon reconstruction and performance in ATLAS using a dynamical, topological cell clustering-based approach'
The ATLAS Collaboration, ATL-PHYS-PUB-2017-022
[2] CERN-EP-2019-169
[3] 'Performance of Ringer in Trigger egamma for WCCI2018'
https://twiki.cern.ch/twiki/pub/AtlasPublic/EgammaTriggerPublicResults/HLT_e28_lhtight_nod0_ivarloose_L1EM24VHIM_et.png
[4] 'Performance of photon triggers for Pb+Pb collisions at 5.02 TeV'
https://twiki.cern.ch/twiki/pub/AtlasPublic/EgammaTriggerPublicResults/PhotonTriggerPerformance_vsFCal_Prelim.png

BACKUP

electron reconstruction



arxiv 1902.04655

Datasets and simulated samples

p-p collision data

2015 - 3.2 fb^{-1}
2016 - 32.9 fb^{-1}
2017 - 43.9 fb^{-1}
2018 - 58.5 fb^{-1}

Pb - Pb collision data

one month in 2015 and 2018
centre of mass energy per nucleon pair
5.02 TeV

Pb - p collisions

at 5.02 TeV and 8.16 TeV per nucleon pair
in 2016

Heavy Ion reference data

from 5.02 TeV p-p collisions in low pile-up conditions

process	generators
$Z \rightarrow ee$	POWHEG-BOX v2 PYTHIA v8.186
$W \rightarrow e\nu$	POWHEG-BOX v2 PYTHIA v8.186
$J/\psi \rightarrow ee$	PYTHIA v8.186
$qg \rightarrow q\gamma$ $q\bar{q} \rightarrow q\gamma$ W/Z production	PYTHIA v8.186
$Z \rightarrow \ell\ell\gamma$	POWHEG-BOX PHOTOS PYTHIA v8.186
$qg \rightarrow q\gamma$ $q\bar{q} \rightarrow g\gamma$ QCD dijet	PYTHIA v8.186
$H \rightarrow \gamma\gamma$	PYTHIA v8.186
radion decay	MADGRAPH5-2.6.0 PYTHIA v8.212

Z tag and probe measurements

Z tag and probe method

tag electron

matched to lowest unprescaled single electron triggers

tight ID, $E_T > 27$ GeV

$|\eta| < 2.47$, outside the transition region

probe electron

15 GeV around Z-mass peak

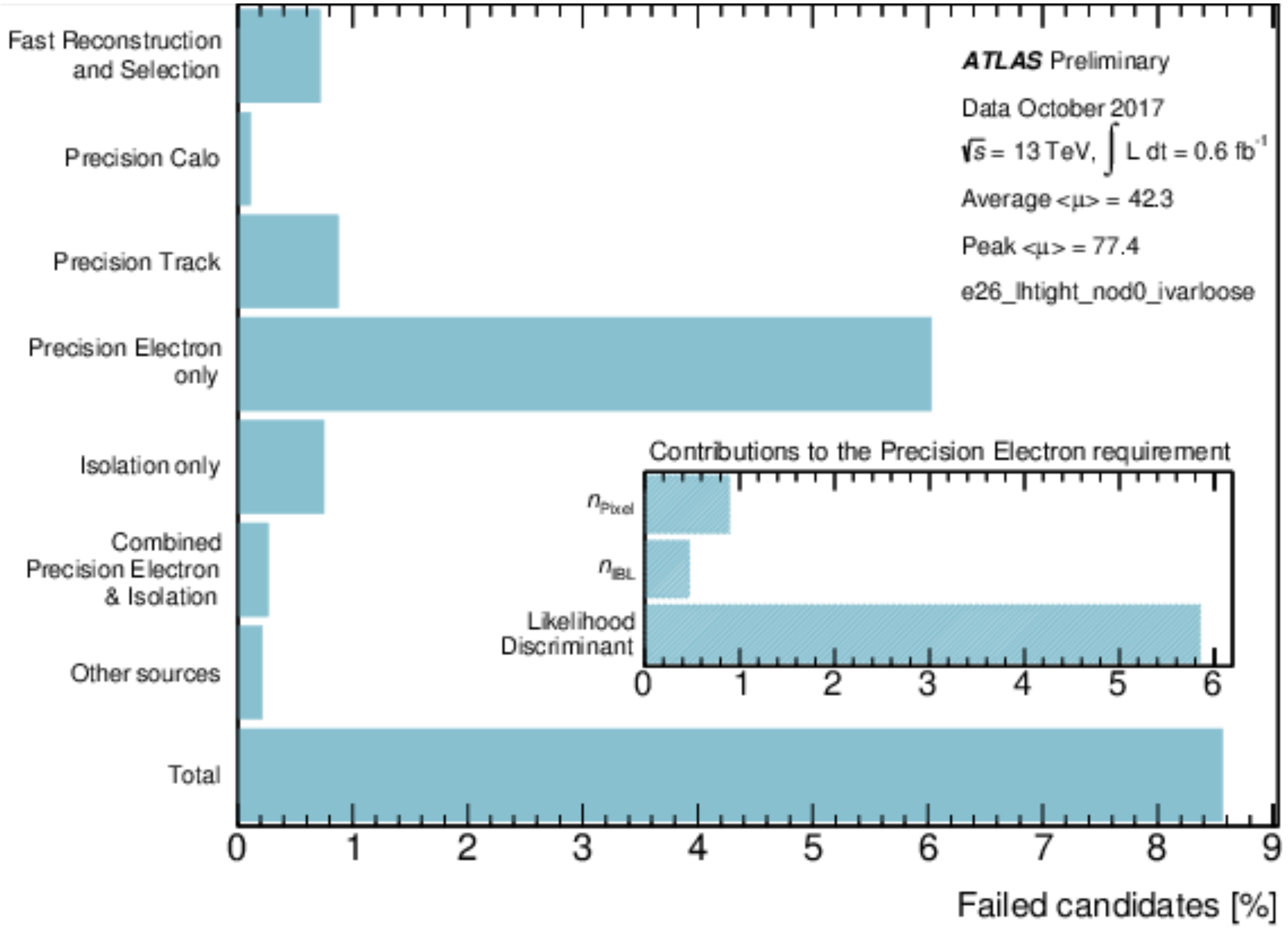
opposite sign to tag electron

systematic uncertainties

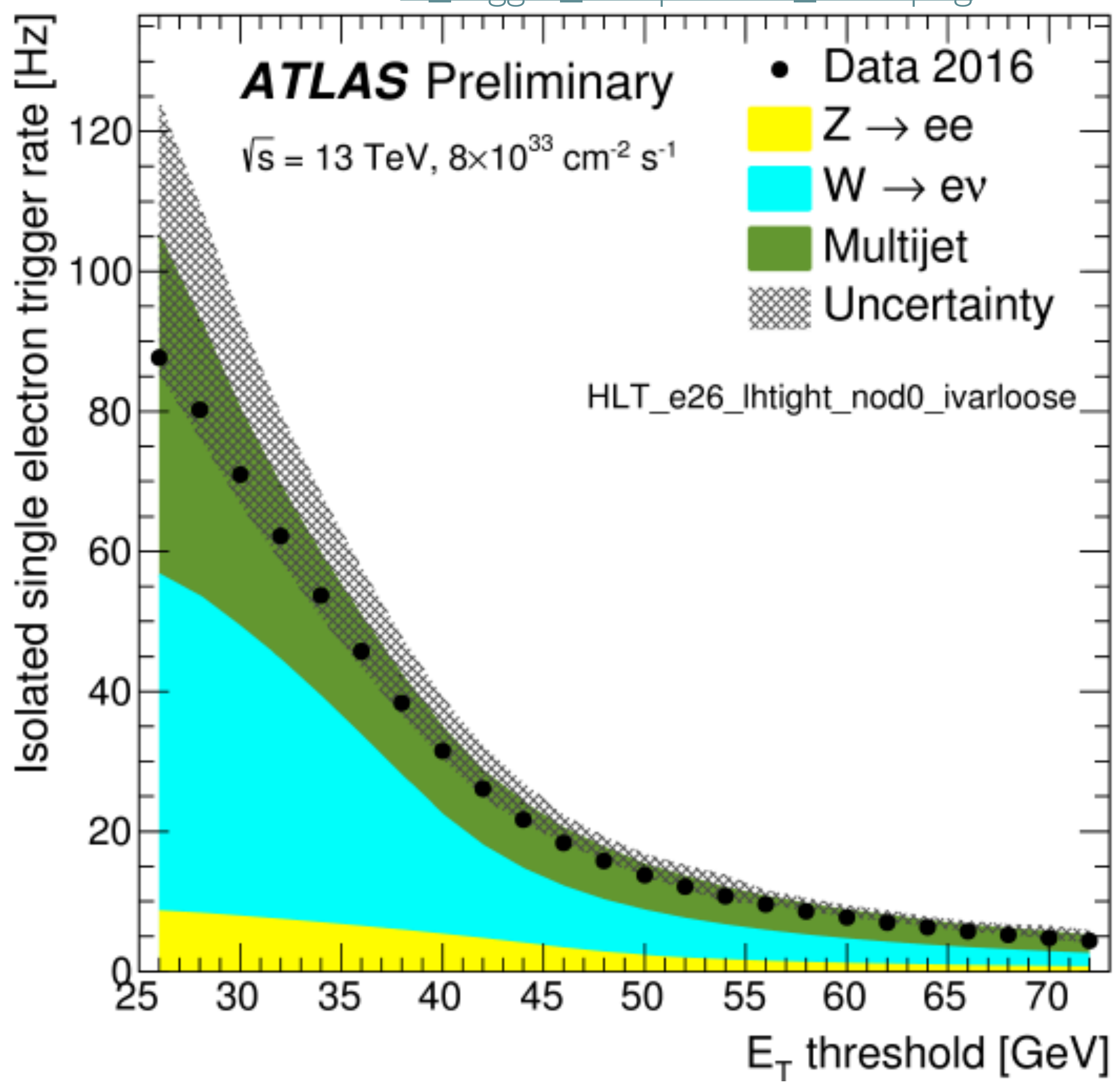
- given by varying tag definition, Z-mass window and background subtraction method
- central value is average of variations
- systematic on central value is standard deviation of all variations
- statistical error on central value is average over statistical uncertainty of variations

trigger inefficiencies

https://twiki.cern.ch/twiki/pub/AtlasPublic/EgammaTriggerPublicResults/e26_lhtight_nod0_ivarloose_IneffisEMLHTight_2017.png



https://twiki.cern.ch/twiki/pub/AtlasPublic/EgammaTriggerPublicResults/el_trigger_composition_8e33.png



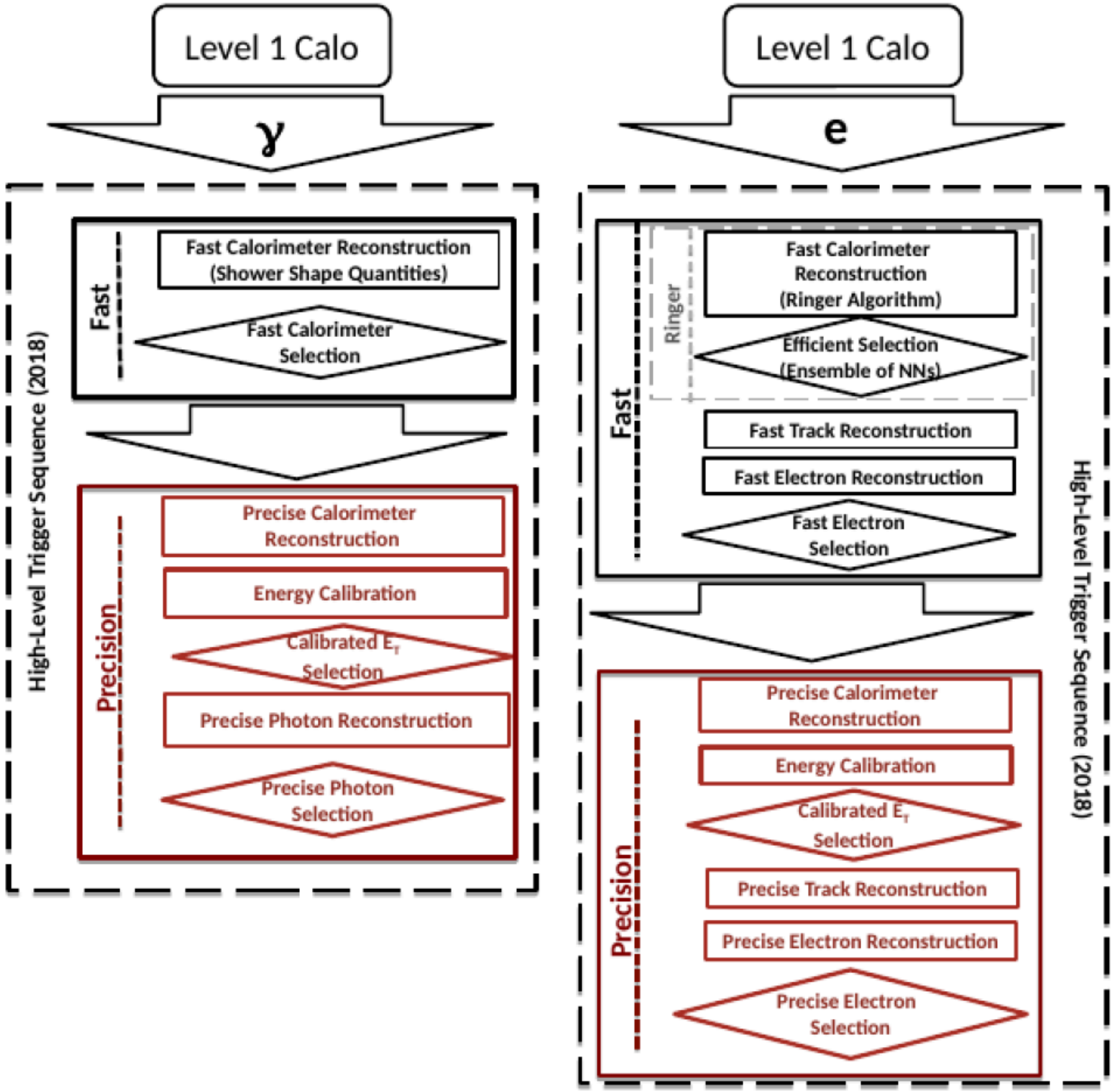
- studies of physics origin of electrons from single electron trigger at HLT shows that main processes are W and Z production

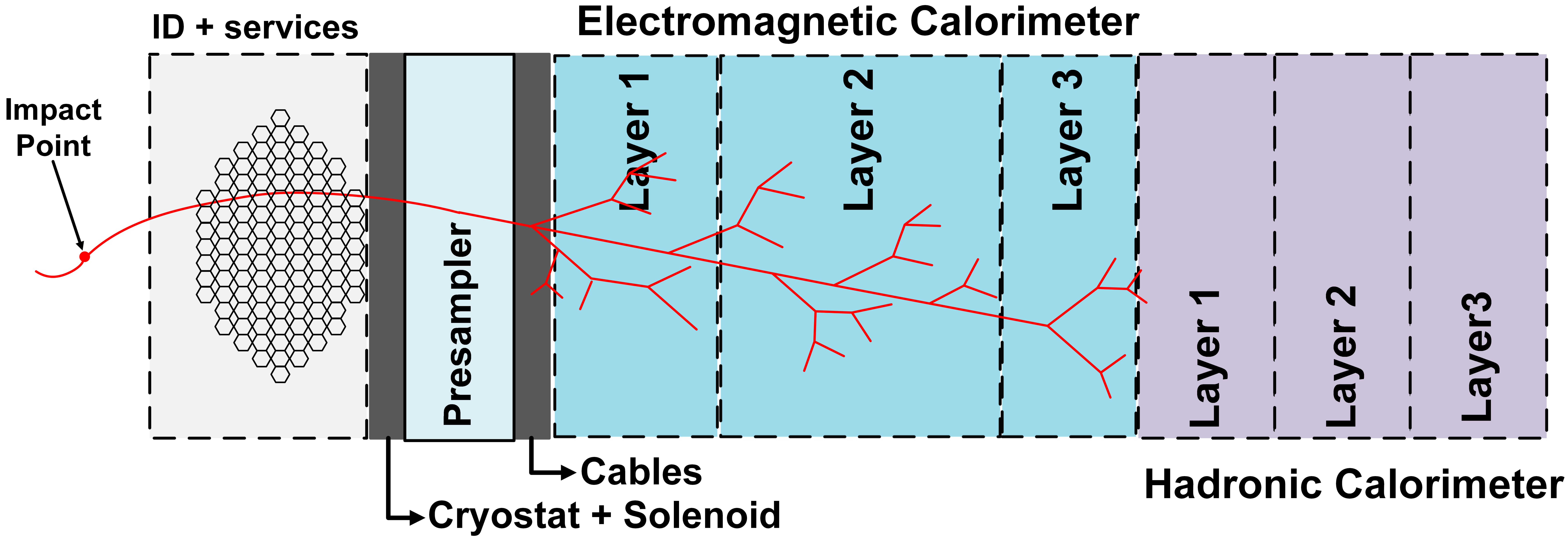
- inefficiency sources for 2017 single electron chain mainly electron identification for tight and isolated trigger

Trigger reconstruction and identification of photons and electrons

Level I	2x2 trigger tower cluster as RoI in EM calorimeter **V**: varying E_T threshold within -2 and +3 GeV of nominal threshold **H**: veto on hadronic leakage **I**: E_T dependent Ecal isolation of cluster
e/γ trigger	• precision reconstruction with sliding window algorithm • no usage of superclusters • use of average number of interactions per crossing instead of number of primary vertices
Photon trigger	• fast algorithm uses only 2nd layer of EM calo, selection on cluster E_T and shower shape parameters • online ID use same cluster shower shapes as the offline ID (without fudging), three working points: '*loose*', '*medium*' (only used online) , '*tight*' • calorimeter only isolation possible • no tracking information

Electron trigger	• fast calorimeter reconstruction cut-based and neural-network ringer algorithm
	• precision selection relying on likelihood discriminant, four working points: *lhvloose, lhloose, lhmedium, lhtight*
	• additional isolation requirement possible *(ivarloose)*
	• differences w.r.t. offline:
	  • trigger reconstruction with poorer resolution than offline
	  • no momentum loss due to bremsstrahlung taken into account




ID + services
Electromagnetic Calorimeter
Impact Point
Presampler
Layer 1
Layer 2
Layer 3
Layer 1
Layer 2
Layer3
Cables
Cryostat + Solenoid
Hadronic Calorimeter