中国科学院高能物理研究所
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ATLAS EXPERIMENT

ATLAS Photon lateral leakage studies 2022+2023 Run-3

CLHCP 2024 QingDao

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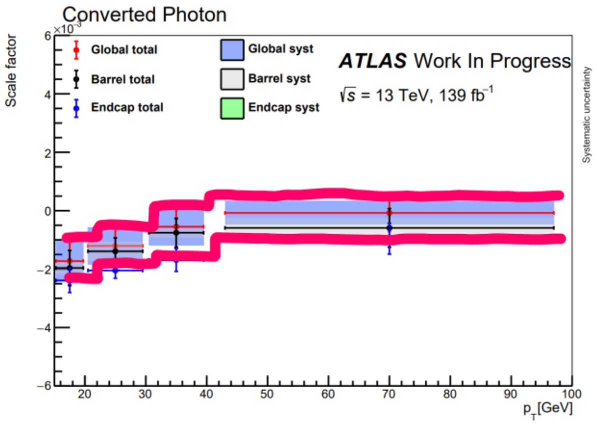
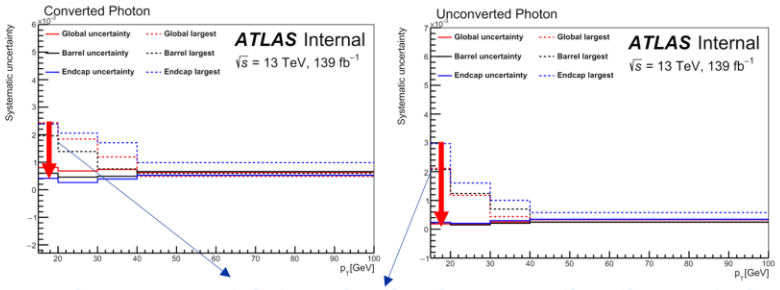
motivation

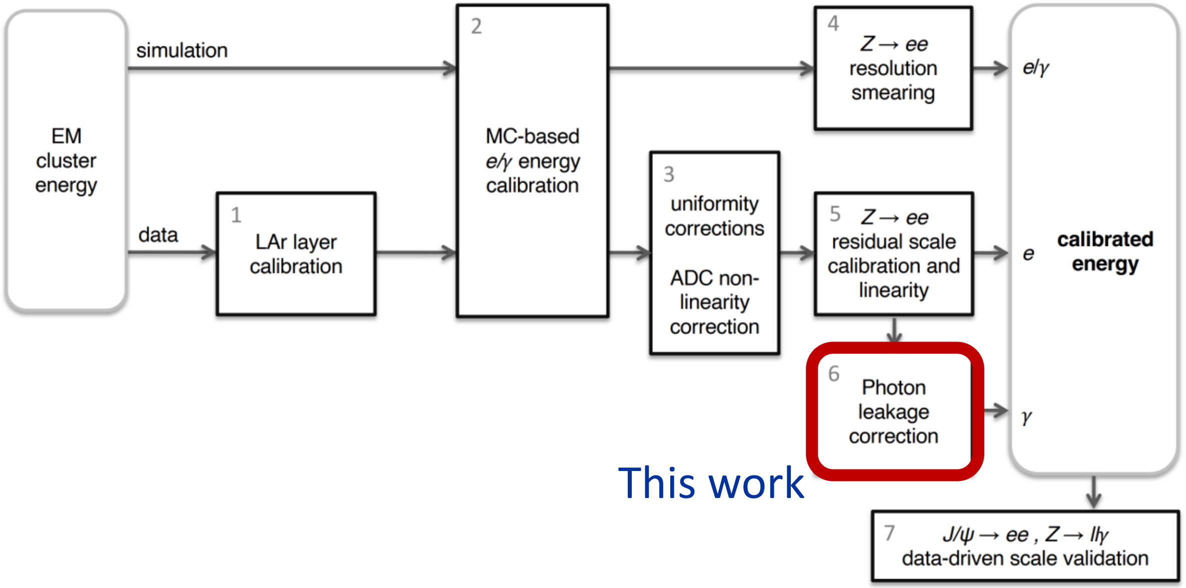
- Calibration for photons is based on electrons in ATLAS.
- Shower shape is not well modeled in MC, and differently between photon and electron.
  - Electron mismodelling is well controlled by electron calibration
- **Previous conservative strategy in Run2**
  - **Only assign the uncertainty with the envelop of the double difference**
  - The idea is **correcting the lateral energy difference between photon and electron in EMC**
- Using $Z \rightarrow ee$ to get electron cluster energy information and $Z \rightarrow ll\gamma$ to get the photons cluster energy information
  - Photons are divided into converted and un-converted for different shower shape
  - Use energy in layer2 for most energy deposition

Envelop of the double difference as uncertainty in Run2

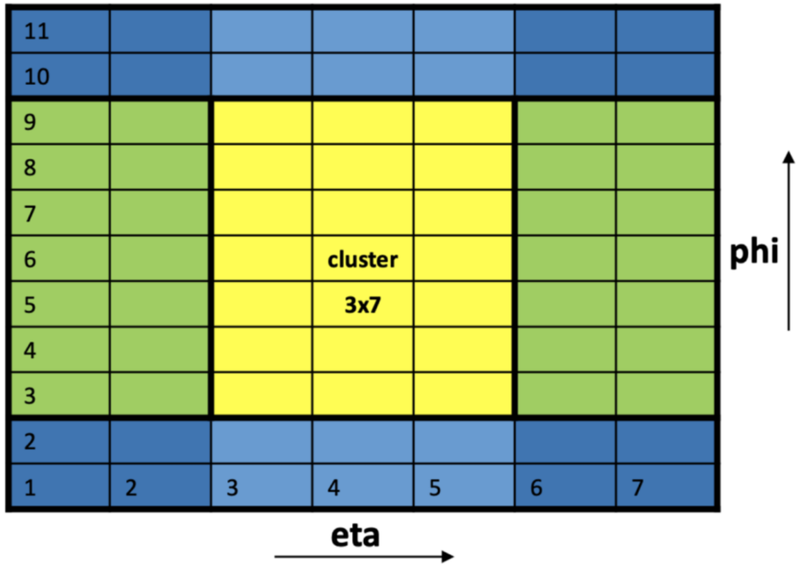




Large uncertainty reduction by correcting the central value with Pt/eta and conversion status dependence



Methodology



An illustration of barrel region

- **Definition of leakage fractions**
  - $l = \frac{E_{s2}(7\times11) - E_{s2}(nominal)}{E_{s2}(nominal)}$
- **Due to the Timing cut issue (link)**
  - Some cells energy are missing in reconstruction step
  - Missing cell energy is stored in Eadded_Lr2
  - Include the missing cell energy in E_nominal
- **Definition of double difference**
  - $\Delta l^{e} - \Delta l^{\gamma} = \left(l^{data} - l^{MC}\right)^{e} - \left(l^{data} - l^{MC}\right)^{\gamma}$
  - Describe the difference between data and MC, electrons and photons
  - The double difference is used as calibration factors for photon leakage
- **Photon conversion**
  - The photons are divided into converted and unconverted photons
  - Due to TRT bugs, the converted photons from TRT are regarded as un-converted photons

Selections

➢ Object selections

Cut	Electron		Photon	Muon
	$Z \to ee$	$Z \to ee\gamma$		
E_T , P_T	E_T> 10 GeV	E_T> 18 GeV	E_T> 10 GeV	P_T>15 GeV
$\|\eta\|$	$\|\eta\|$<2.47 exclude [1.37,1.52]	$\|\eta\|$<2.47 exclude [1.37,1.52]	$\|\eta\|$<2.37 exclude [1.37,1.52]	$\|\eta\|$<2.7
d_0 significance	<10	<10		<10
$\|z_{PV}\|$	<10 mm	<10mm		<10 mm
ID	Medium	Loose	Tight	Medium
ISO	Loose	Loose	FixedCutLoose	FCLoose

➢ Event selections

- GRL PV EQ Trigger
- $m_{ee} \in (75GeV, 105GeV)$ for $Z \to ee$
- Overlap removal for $Z \to ll\gamma$: $\Delta R(l,\gamma) > 0.4$
- $m_{ll} \in (40GeV, 83GeV)$ and $m_{ll\gamma} \in (83GeV, 100GeV)$ for $Z \to ll\gamma$

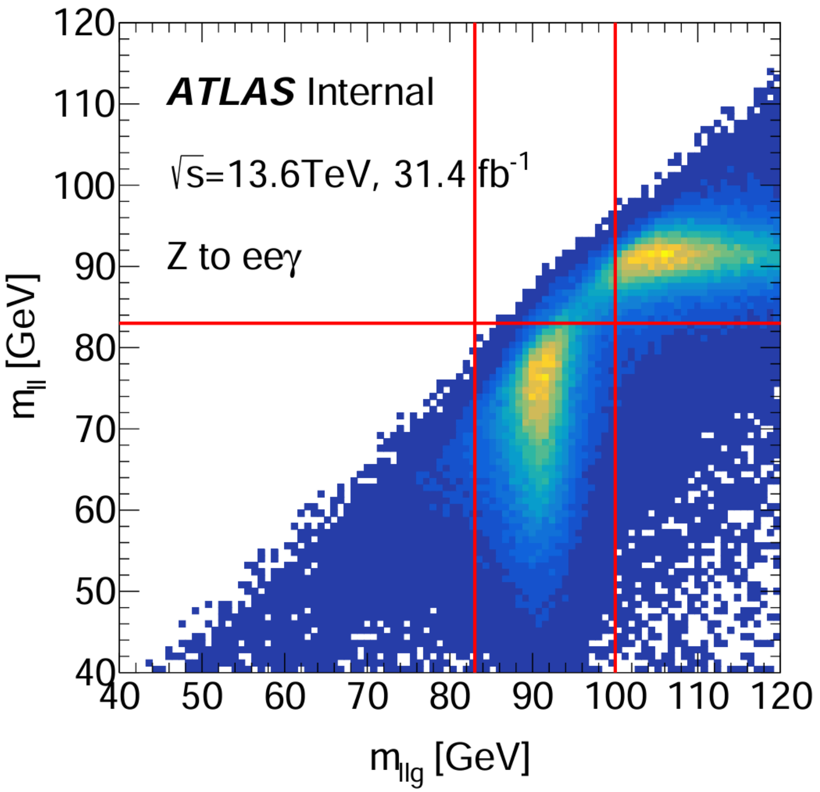
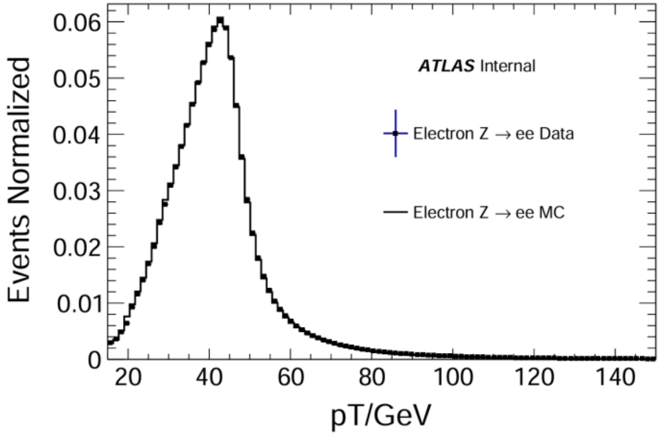
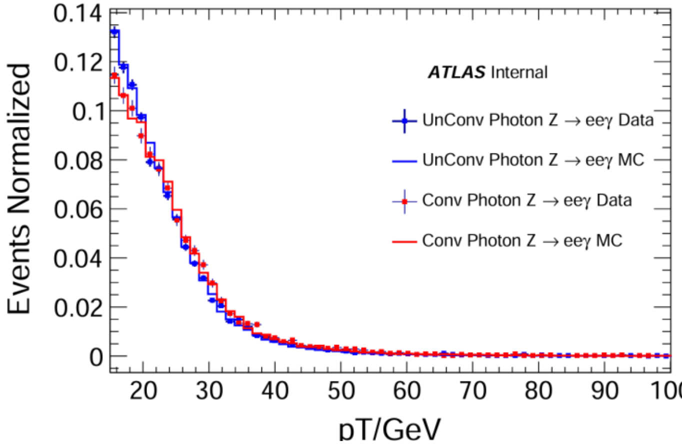


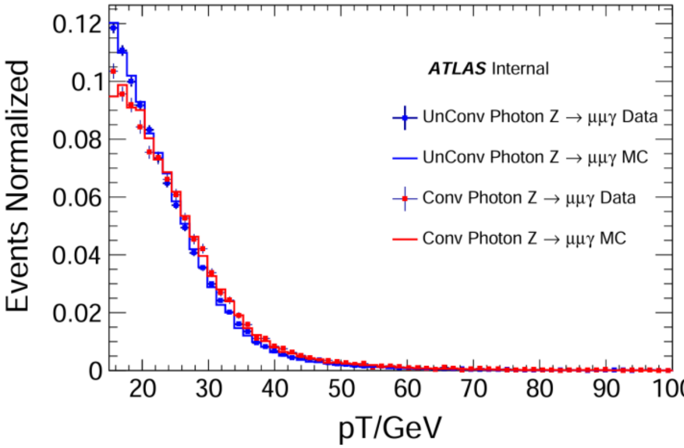
Figure 3.1: An plot shows the 2D distribution and why requiring mass window cuts.

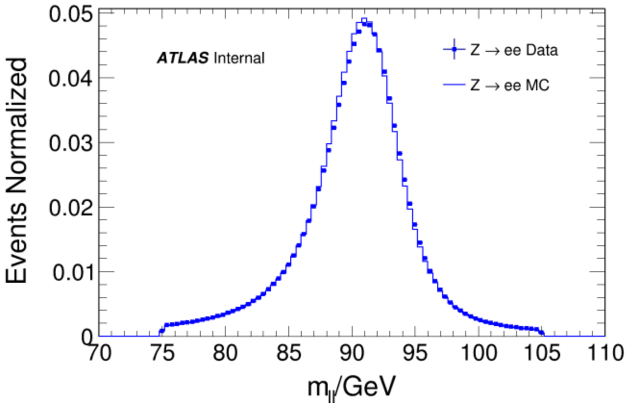
The distribution after selection

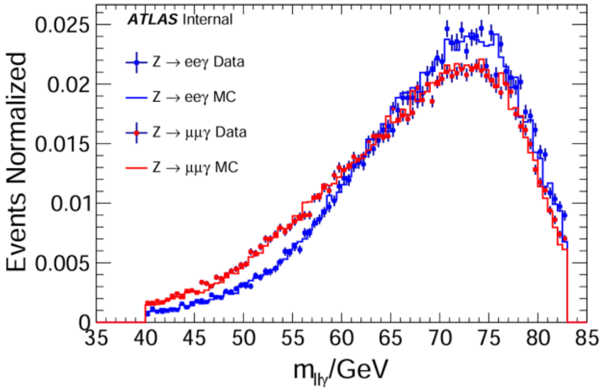
- **The distributions after selections are shown here**
  - The data-MC agreement is good enough to use
- **The eta/pT binning**
  - Considering the statistical
  - The eta is divided by barrel and end-cup in the end
  - The pT binning is determined to be:
    - $15 - 20 - 30 - 40 - \infty$

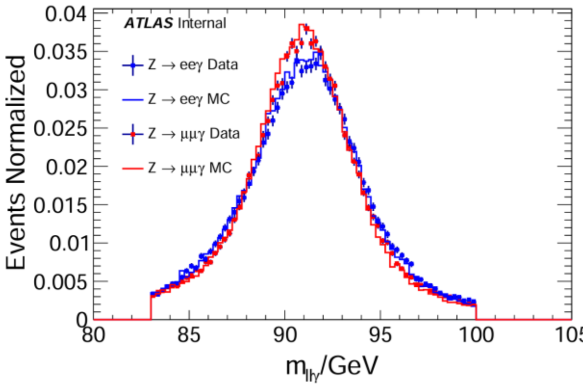








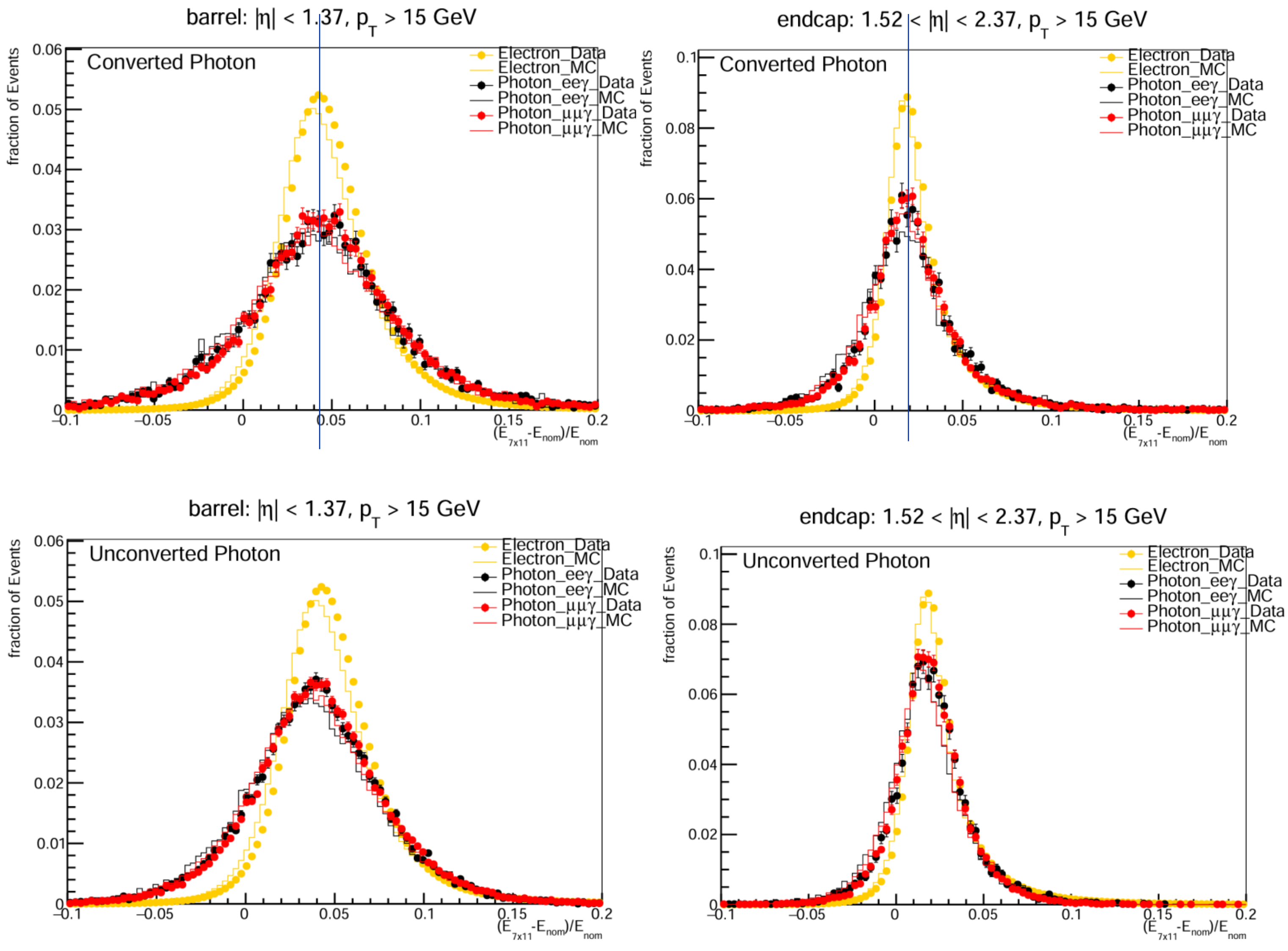




Lateral energy leakage distribution

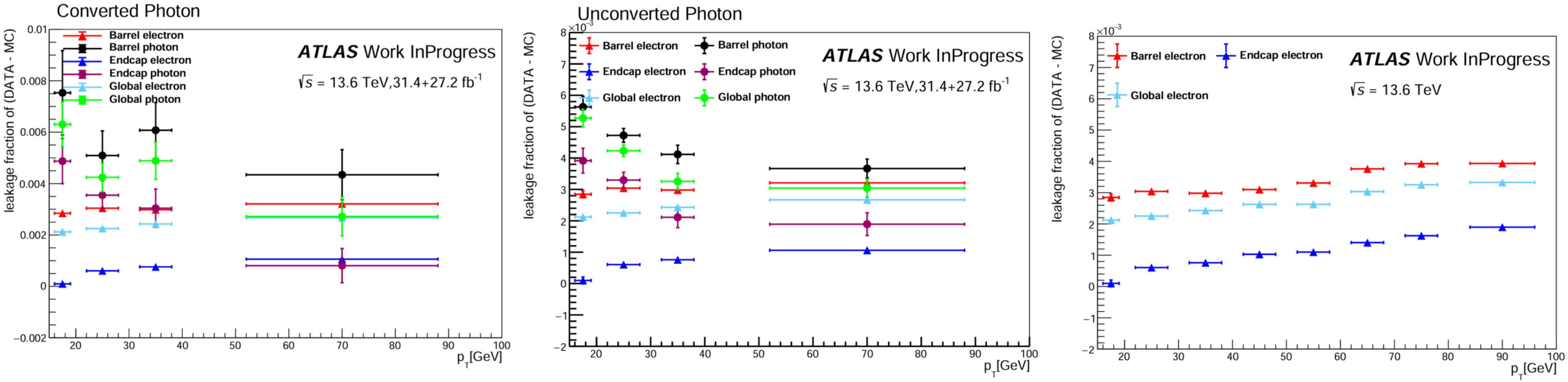
- **Mean value** of leakage histogram:
  - Regarded as the leakage fraction value
  - Leakage fraction in end-cup is lower than barrel

- The **standard error of mean** is regarded as its **statistical uncertainty**

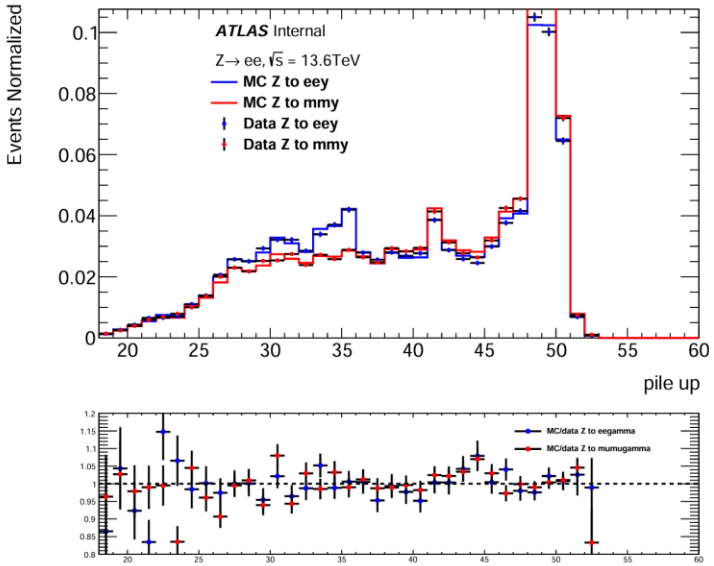


Data-MC difference distributions on pT and eta

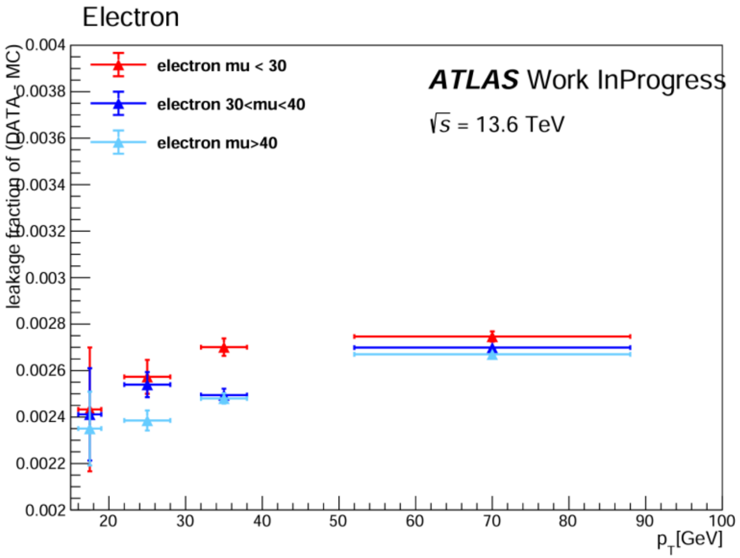
- **The Data-MC difference are shown for electrons and photons**
- **Circle markers are photons and triangle markers are electrons**
  - Finer bins for **electrons** since larger statistical
  - The Data-MC difference increase by pT for **electrons**
  - **Mis-modelling in barrel is higher than end-cap** for both electron and photon

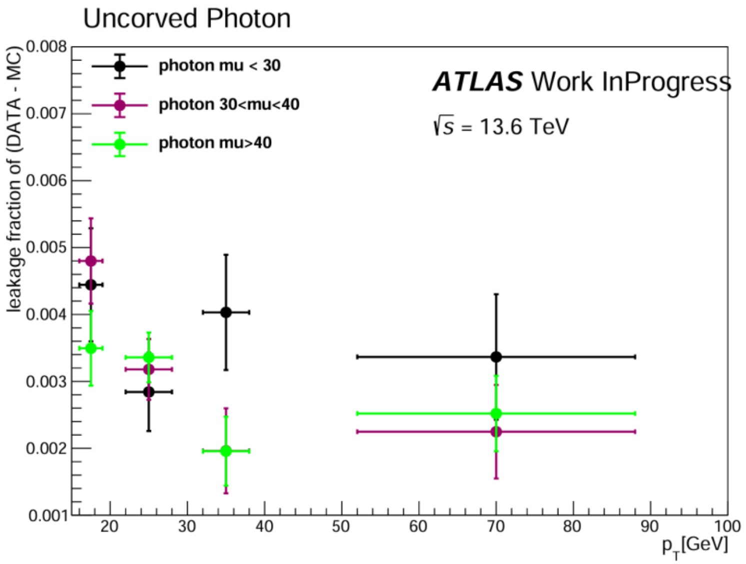


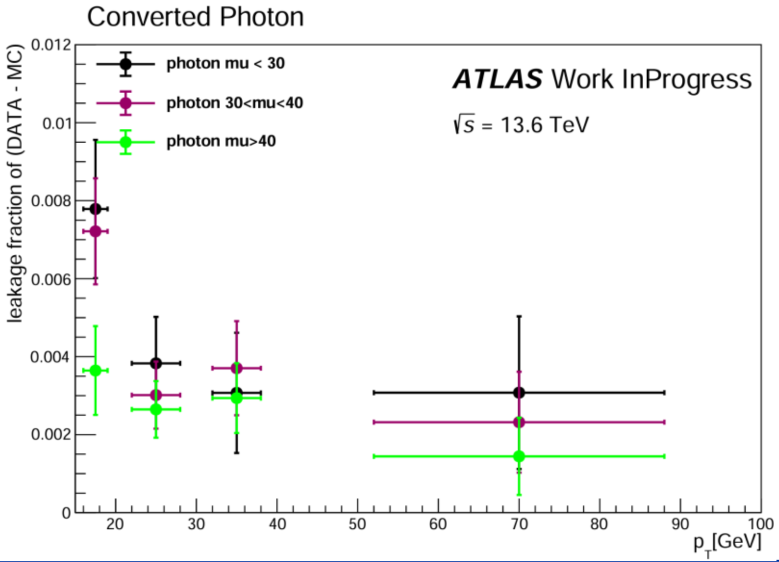
Data-MC difference distributions on pile up



- **The pile up distribution of $Z \to ee\gamma$ and $Z \to \mu\mu\gamma$ is shown here**
  - Divided into three subregions
    - Pileup<30; 30≤Pileup<40 ;40≤Pileup
- **The data-MC distribution dependence is shown below**
  - Slight influence on unconverted photon and electron
  - Higher influence on low pt converted photon, but large uncertainty here

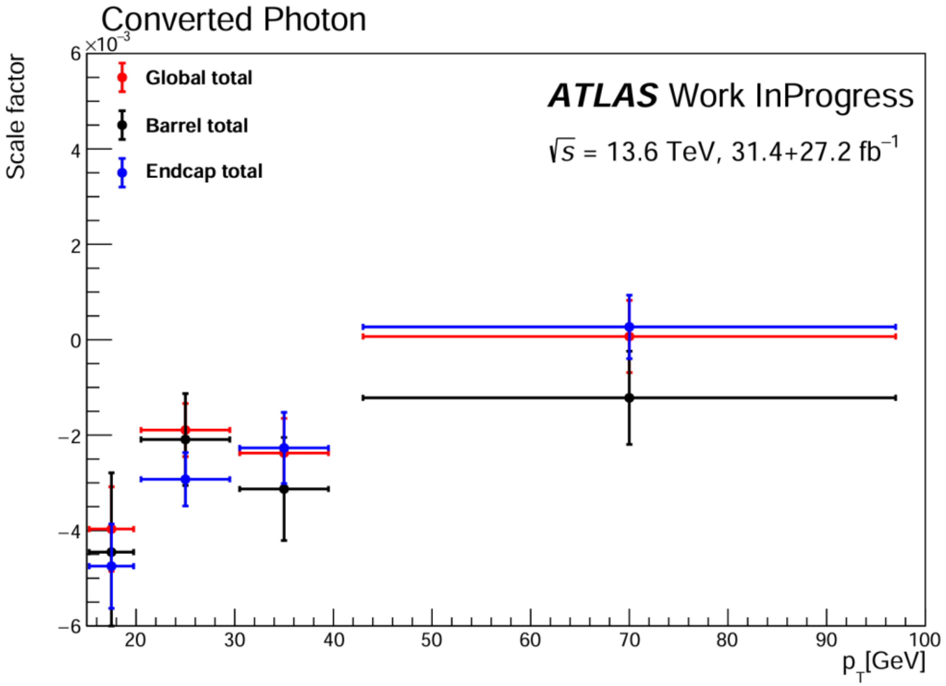


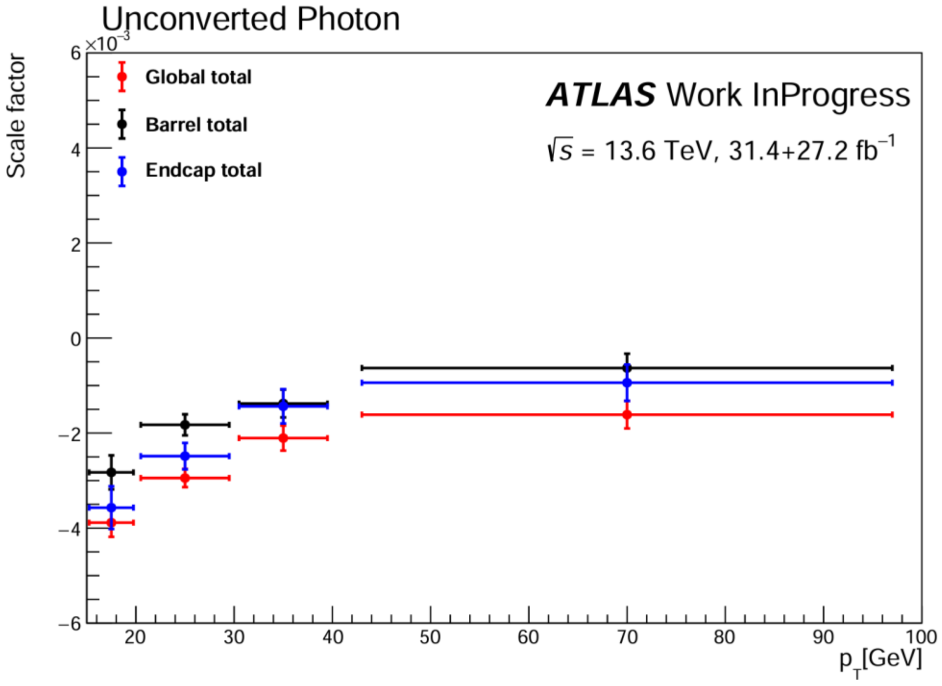




Double difference distributions

- **The double difference conveys the difference of lateral leakage mis-modeling between electrons and photons**
  - Double difference in barrel is higher than end-cap for both converted and unconverted photons





The influence of Photon ID/ISO

- **The nominal Photons ID and ISO is tight and fixcutloose**
  - The ID is changed to loose (using 2015-2018 and Rel 21 recommendation, only tight and loose)
  - The ISO is changed to FixedCutTightCaloOnly and FixedCutTight
- **The double difference value before the conversion reweighting is shown in table below**
  - The **ISO is would change the result a lot** for converted photons in barrel
  - The **difference would decrease with pt in most situations**
  - The **difference from photon ID is mush smaller than ISO**

Double difference(‰)	ID/ISO	$15GeV < p_T < 20GeV$	$20GeV < p_T < 30GeV$	$30GeV < p_T < 40GeV$	$p_T > 40GeV$
El - Conv, barrel	Tight/FixedCutLoose	-0.469 ± 0.165	-0.205 ± 0.096	-0.309 ± 0.108	-0.113 ± 0.098
	Tight/FixedCutTight	-0.525 ± 0.157	-0.160 ± 0.097	-0.288 ± 0.115	-0.206 ± 0.107
ID	Tight/FixedCutTightCaloOnly	-0.460 ± 0.156	-0.161 ± 0.095	-0.290 ± 0.113	-0.154 ± 0.106
	Loose/FixedCutTight	-0.541 ± 0.159	-0.138 ± 0.098	-0.283 ± 0.115	-0.176 ± 0.107

Table 7.1: The double difference results in different WPs for barrel converted photons

Double difference(‰)	ID/ISO	$15GeV < p_T < 20GeV$	$20GeV < p_T < 30GeV$	$30GeV < p_T < 40GeV$	$p_T > 40GeV$
El - Unconv, barrel	Tight/FixedCutLoose	-0.278 ± 0.036	-0.168 ± 0.022	-0.114 ± 0.029	-0.046 ± 0.030
	Tight/FixedCutTight	-0.295 ± 0.037	-0.198 ± 0.024	-0.122 ± 0.031	-0.060 ± 0.034
ID	Tight/FixedCutTightCaloOnly	-0.296 ± 0.036	-0.193 ± 0.023	-0.125 ± 0.031	-0.059 ± 0.034
	Loose/FixedCutTight	-0.285 ± 0.037	-0.190 ± 0.024	-0.123 ± 0.032	-0.057 ± 0.034

Table 7.3: The double difference results in different WPs for barrel unconverted photons

Systematics uncertainty

$\mu\mu\gamma$ fractions taken from Internal Note are used in this study

- Only conversion reconstruction mis-modeling is considered as Systematics uncertainty
- The number of photons reconstructed as converted/unconverted is:

$$N_{conv}^{reco} = Nf_{conv} \times f_{reco} + N(1 - f_{conv}) \times f_{fake}$$

$$N_{unconv}^{reco} = N(1 - f_{conv}) \times (1 - f_{fake}) + Nf_{conv} \times (1 - f_{reco})$$

- f_{conv} is the probability of a photon to covert, f_{reco} is the conversion reconstruction efficiency, f_{fake} is the conversion fake rate

$\|\eta\|$ regions	f_{conv}		f_{reco}		f_{fake}	
	Data	MC	Data	MC	Data	MC
$\|\eta\| \in [0,0.6)$	0.148 ± 0.010	0.145	0.764 ± 0.037	0.850	0.076 ± 0.004	0.040
$\|\eta\| \in [0.6,0.8)$	0.234 ± 0.016	0.271	0.804 ± 0.040	0.774	0.036 ± 0.003	0.022
$\|\eta\| \in [0.8,1.37)$	0.234 ± 0.016	0.271	0.804 ± 0.040	0.774	0.036 ± 0.003	0.022
$\|\eta\| \in [1.52,1.81)$	0.438 ± 0.026	0.415	0.771 ± 0.043	0.915	0.028 ± 0.016	0.037
$\|\eta\| \in [1.81,2.01)$	0.521 ± 0.011	0.516	0.582 ± 0.010	0.653	0.010 ± 0.005	0.012
$\|\eta\| \in [2.01,2.37)$	0.521 ± 0.011	0.516	0.582 ± 0.010	0.653	0.010 ± 0.005	0.012

Systematics uncertainty

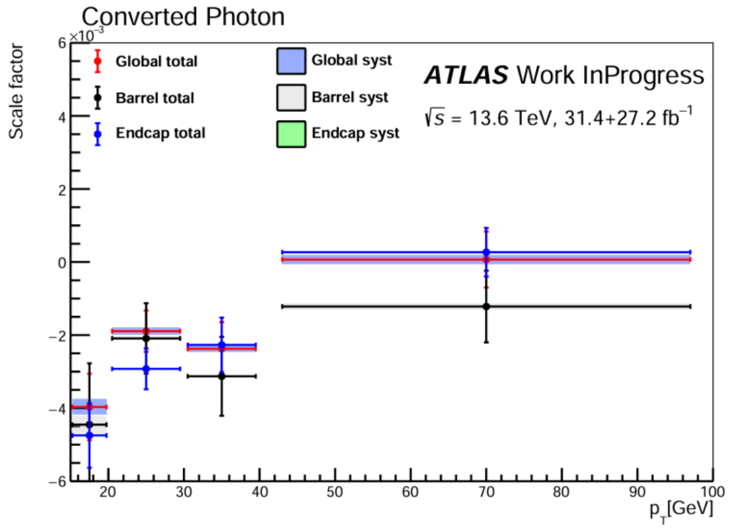
- To correct for the difference between MC and data, weights are applied to MC samples:
  - for a true converted photon reconstructed as unconverted: $\frac{f_{conv}^{data}(1-f_{reco}^{data})}{f_{conv}^{MC}(1-f_{reco}^{MC})}$
  - for a true unconverted photon reconstructed as unconverted : $\frac{(1-f_{conv}^{data})(1-f_{fake}^{data})}{(1-f_{conv}^{MC})(1-f_{fake}^{MC})}$
  - for a true converted photon reconstructed as converted : $\frac{f_{conv}^{data}f_{reco}^{data}}{f_{conv}^{MC}f_{reco}^{MC}}$
  - for a true unconverted photon reconstructed as converted : $\frac{(1-f_{conv}^{data})f_{fake}^{data}}{(1-f_{conv}^{MC})f_{fake}^{MC}}$

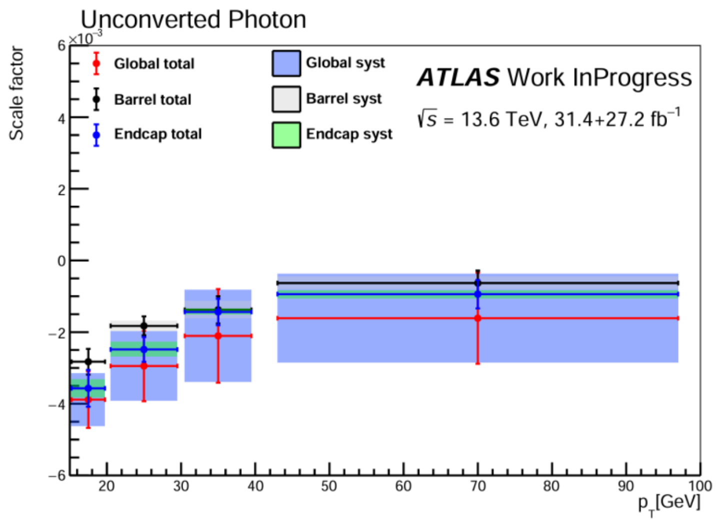
Weight	Reco C/True C	Reco C/True U	Reco U/True C	Reco U/True U
$\|\eta\| < 0.6$	0.917 ± 0.106	1.893 ± 0.122	1.606 ± 0.360	0.959 ± 0.015
$0.6 < \|\eta\| < 0.8$	0.897 ± 0.106	1.719 ± 0.179	0.749 ± 0.204	1.036 ± 0.025
$0.8 < \|\eta\| < 1.37$	0.897 ± 0.106	1.719 ± 0.179	0.749 ± 0.204	1.036 ± 0.025
$1.52 < \|\eta\| < 1.81$	0.889 ± 0.102	0.727 ± 0.449	2.843 ± 0.703	0.970 ± 0.061
$1.81 < \|\eta\| < 2.01$	0.900 ± 0.034	0.825 ± 0.431	1.216 ± 0.055	0.992 ± 0.028
$2.01 < \|\eta\| < 2.37$	0.900 ± 0.034	0.825 ± 0.431	1.216 ± 0.055	0.992 ± 0.028

The leakage factors at FixedCutLoose ISO

- The ID and ISO work point is Tight and fixcutloose
- Due to the change of TRT converted photon definition, the systematic uncertainty form photon conversation are very large. How to deal with it is not decided yet

Scale factor(%)	$15GeV < p_T < 20GeV$	$20GeV < p_T < 30GeV$	$30GeV < p_T < 40GeV$	$p_T > 40GeV$
El - Conv, barrel	$-0.445 \pm 0.166 \pm 0.023$	$-0.209 \pm 0.096 \pm 0.004$	$-0.313 \pm 0.108 \pm 0.003$	$-0.122 \pm 0.098 \pm 0.008$
El - Conv, end-cap	$-0.475 \pm 0.088 \pm 0.003$	$-0.292 \pm 0.056 \pm 0.002$	$-0.227 \pm 0.075 \pm 0.001$	$0.027 \pm 0.067 \pm 0.002$
El - Unconv, barrel	$-0.283 \pm 0.036 \pm 0.004$	$-0.183 \pm 0.022 \pm 0.014$	$-0.138 \pm 0.029 \pm 0.024$	$-0.063 \pm 0.030 \pm 0.017$
El - Unconv, end-cap	$-0.357 \pm 0.045 \pm 0.025$	$-0.248 \pm 0.028 \pm 0.021$	$-0.144 \pm 0.036 \pm 0.008$	$-0.094 \pm 0.038 \pm 0.011$





Summary

- **Performed the photon leakage measurement in Run3, but still work in progress**
  - The data-MC differences , double difference and the dependences on eta, pt and pile-up are investigated
  - The measurement are performed in different ISO work points
- **The uncertainty is mainly statistical uncertainty**
  - The systematics uncertainty from photon conversation need to be reestimate
- **Need further understand the influence of ISO and ID work point**
  - Considering as systematics uncertainty?
- **Next:**
  - Include data and MC this year for much higher statistic

Additional slides

Samples and GRL

- **Data: ptag p6000/p5859**

2*$Z \to ee$	data22_13p6TeV.periodAllYear.physics_Main.PhysCont.DAOD_EGAM1.grp22_v01_p6000
	data23_13p6TeV.periodAllYear.physics_Main.PhysCont.DAOD_EGAM1.grp23_v01_p5859
2*$Z \to ee\gamma$	data22_13p6TeV.periodAllYear.physics_Main.PhysCont.DAOD_EGAM3.grp22_v01_p6000
	data23_13p6TeV.periodAllYear.physics_Main.PhysCont.DAOD_EGAM3.grp23_v01_p5859
2*$Z \to \mu\mu\gamma$	data22_13p6TeV.periodAllYear.physics_Main.PhysCont.DAOD_EGAM4.grp22_v01_p6000
	data23_13p6TeV.periodAllYear.physics_Main.PhysCont.DAOD_EGAM4.grp23_v01_p5859

Table 2.1: Data samples used for $Z \to ee$, $Z \to ee\gamma$ and $Z \to \mu\mu\gamma$ channel.

- **MC: Amitag r14622_p5660/r15224_p6080**

2*$Z \to ee$	mc23_13p6TeV.601189.PhPy8EG_AZNLO_Zee.deriv.DAOD_EGAM1.e8514_s4111_r14622_p5660
	mc23_13p6TeV.601189.PhPy8EG_AZNLO_Zee.deriv.DAOD_EGAM1.e8514_s4159_r15224_p6080
2*$Z \to ee\gamma$	mc23_13p6TeV.700770.Sh_2214_eegamma.deriv.DAOD_EGAM3.e8514_s4111_r14622_p5660
	mc23_13p6TeV.700770.Sh_2214_eegamma.deriv.DAOD_EGAM3.e8514_s4159_r15224_p6080
2*$Z \to \mu\mu\gamma$	mc23_13p6TeV.700771.Sh_2214_mumugamma.deriv.DAOD_EGAM4.e8514_s4111_r14622_p5660
	mc23_13p6TeV.700771.Sh_2214_mumugamma.deriv.DAOD_EGAM4.e8514_s4159_r15224_p6080

Table 2.2: MC samples used for $Z \to ee$, $Z \to ee\gamma$ and $Z \to \mu\mu\gamma$ channel.

Triggers and GRLs

➢ Triggers

- Only electron and muon triggers

Year	SingleElectron	DiElectron	SingleMuon	DiMuon
2022	HLT_e26_lhtight_ivarloose_L1EM22VHI	HLT_2e17_lhvloose_L12EM15VHI	HLT_mu24_ivarmedium_L1MU14FCH	HLT_2mu14_L12MU8F
	HLT_e60_lhmedium_L1EM22VHI	HLT_2e24_lhvloose_L12EM20VH	HLT_mu50_L1MU14FCH	
	HLT_e140_lhloose_L1EM22VHI		HLT_mu60_0eta105_msonly_L1MU14FCH	
2023	HLT_e26_lhtight_ivarloose_L1eEM26M	HLT_2e17_lhvloose_L12eEM18M	HLT_mu24_ivarmedium_L1MU14FCH	HLT_2mu14_L12MU8F
	HLT_e60_lhmedium_L1eEM26M	HLT_2e24_lhvloose_L12eEM24L	HLT_mu50_L1MU14FCH	
	HLT_e140_lhloose_L1eEM26M		HLT_mu60_0eta105_msonly_L1MU14FCH	

Table 3.2: List of triggers used in the data selection

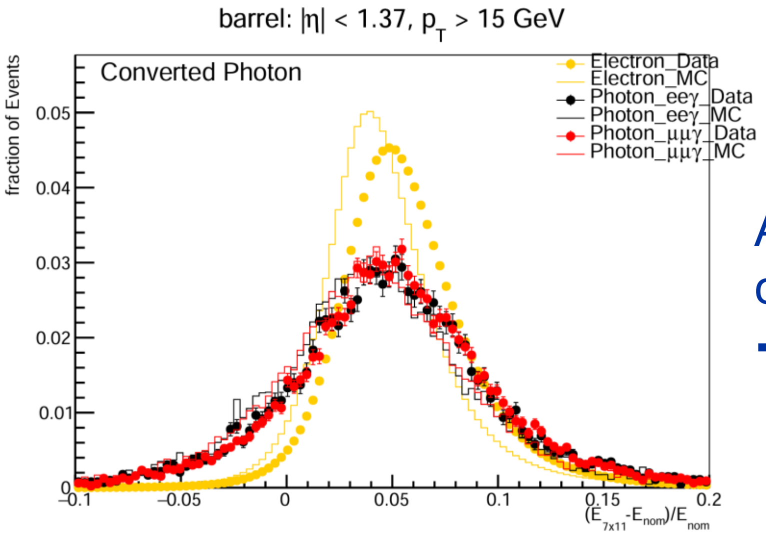
➢ GRL:

Year	Good Run List
2022	data22_13p6TeV.periodAllYear_DetStatus-v109-pro28-04_MERGED_PHYS_StandardGRL_All_Good_25ns_ignore_TRIGMUO_TRIGLAR.xml
2023	data23_13p6TeV.periodAllYear_DetStatus-v110-pro31-06_MERGED_PHYS_StandardGRL_All_Good_25ns_ignoreTRIG_JETCTPIN.xml

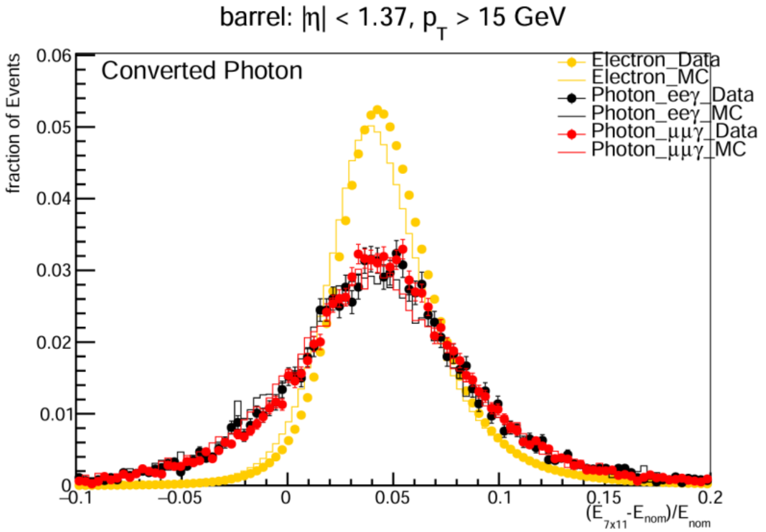
Table 3.1: Good Run Lists used for different years

The influence of timing cut issue

- **Leakage fraction definition:**
  - $l = \frac{E_{s2}(7\times11) - E_{s2}(nominal)}{E_{s2}(nominal)}$
  - $E_{s2}(nominal)$ is the reconstructed energy in Layer2
- **Due to the Timing cut issue (link)**
  - Missing cell energy is stored in Eadded_Lr2
  - $E_{s2}(nominal) = \text{cluster} \rightarrow \text{energyBE}(2) + \text{electron} \rightarrow \text{auxdata} < \text{float} > (\text{"Eadded\_Lr2"})$
  - The agreement of the leakage fraction between data and MC would be improved after including the missing energy, but there would still be some difference between data and MC.



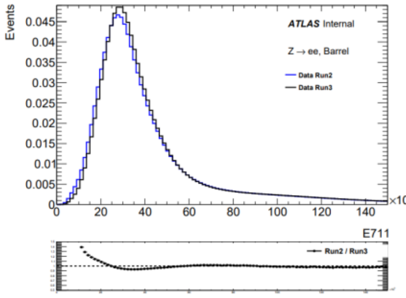
Add energy from missing cell (Eadded_Lr2)



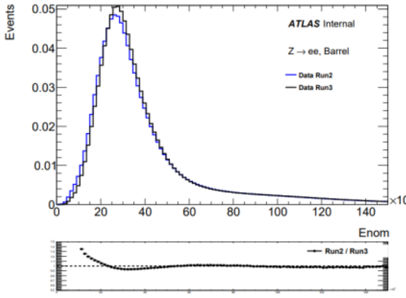
The comparison between Run2 and Run3

- **Compare the $E_{nominal}, E_{7\times11}$ and *leakage* distribution**
  - Compare with Run2 Ntuple
  - Difference is observed in leakage distribution

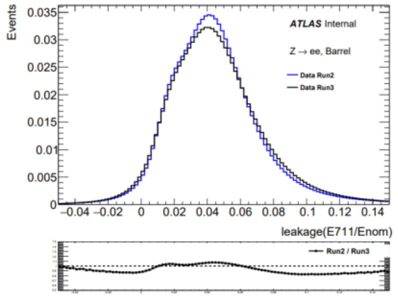
Electrons, Barrel



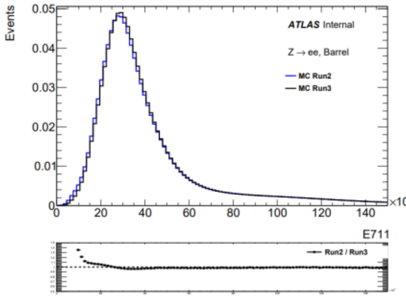
(a)



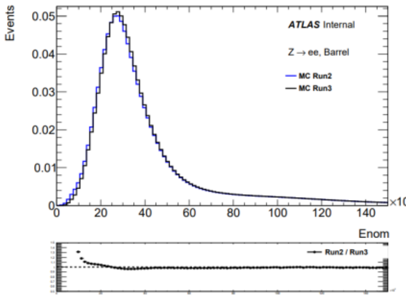
(b)



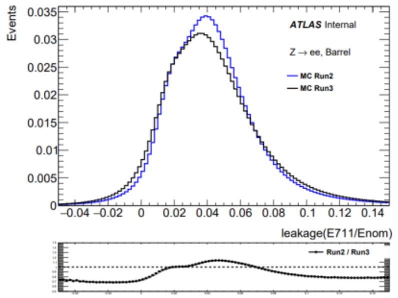
(c)



(d)

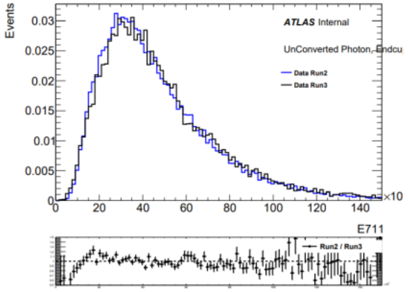


(e)

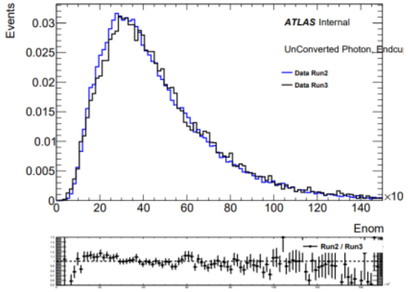


(f)

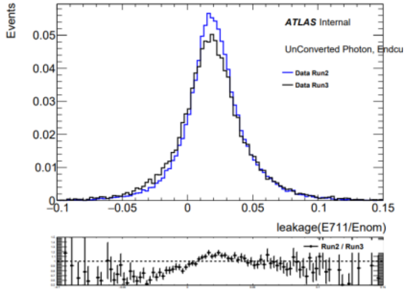
Unconverted Photons, End-cup



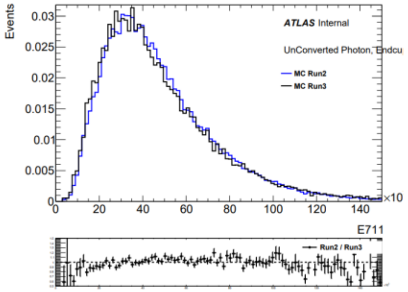
(g)



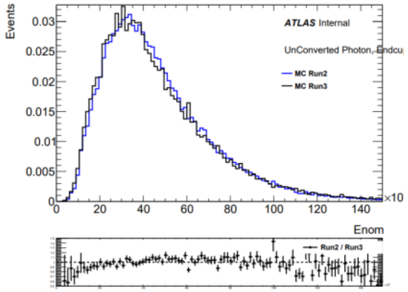
(h)



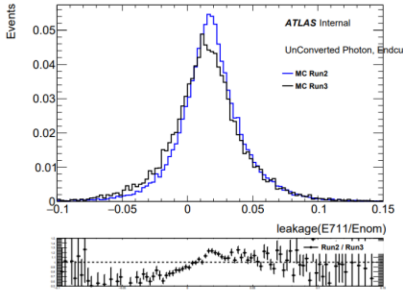
(i)



(j)



(k)



(l)

Full photon ID and ISO influence table

Double difference(%)	ID/ISO	$15GeV < p_T < 20GeV$	$20GeV < p_T < 30GeV$	$30GeV < p_T < 40GeV$	$p_T > 40GeV$
El - Conv, barrel	Tight/FixedCutLoose	-0.469 ± 0.165	-0.205 ± 0.096	-0.309 ± 0.108	-0.113 ± 0.098
	Tight/FixedCutTight	-0.525 ± 0.157	-0.160 ± 0.097	-0.288 ± 0.115	-0.206 ± 0.107
	Tight/FixedCutTightCaloOnly	-0.460 ± 0.156	-0.161 ± 0.095	-0.290 ± 0.113	-0.154 ± 0.106
	Loose/FixedCutTight	-0.541 ± 0.159	-0.138 ± 0.098	-0.283 ± 0.115	-0.176 ± 0.107

Table 7.1: The double difference results in different WPs for barrel converted photons

Double difference(%)	ID/ISO	$15GeV < p_T < 20GeV$	$20GeV < p_T < 30GeV$	$30GeV < p_T < 40GeV$	$p_T > 40GeV$
El - Conv, end-cap	Tight/FixedCutLoose	-0.477 ± 0.088	-0.294 ± 0.056	-0.228 ± 0.075	0.025 ± 0.067
	Tight/FixedCutTight	-0.447 ± 0.094	-0.371 ± 0.060	-0.239 ± 0.079	-0.008 ± 0.072
	Tight/FixedCutTightCaloOnly	-0.404 ± 0.091	-0.329 ± 0.058	-0.228 ± 0.078	0.010 ± 0.073
	Loose/FixedCutTight	-0.427 ± 0.096	-0.354 ± 0.061	-0.250 ± 0.081	-0.017 ± 0.073

Table 7.2: The double difference results in different WPs for end-cup converted photons

Double difference(%)	ID/ISO	$15GeV < p_T < 20GeV$	$20GeV < p_T < 30GeV$	$30GeV < p_T < 40GeV$	$p_T > 40GeV$
El - Unconv, barrel	Tight/FixedCutLoose	-0.278 ± 0.036	-0.168 ± 0.022	-0.114 ± 0.029	-0.046 ± 0.030
	Tight/FixedCutTight	-0.295 ± 0.037	-0.198 ± 0.024	-0.122 ± 0.031	-0.060 ± 0.034
	Tight/FixedCutTightCaloOnly	-0.296 ± 0.036	-0.193 ± 0.023	-0.125 ± 0.031	-0.059 ± 0.034
	Loose/FixedCutTight	-0.285 ± 0.037	-0.190 ± 0.024	-0.123 ± 0.032	-0.057 ± 0.034

Table 7.3: The double difference results in different WPs for barrel unconverted photons

Double difference(%)	ID/ISO	$15GeV < p_T < 20GeV$	$20GeV < p_T < 30GeV$	$30GeV < p_T < 40GeV$	$p_T > 40GeV$
El - Unconv, end-cap	Tight/FixedCutLoose	-0.382 ± 0.041	-0.269 ± 0.025	-0.135 ± 0.033	-0.083 ± 0.036
	Tight/FixedCutTight	-0.403 ± 0.043	-0.248 ± 0.027	-0.169 ± 0.036	-0.072 ± 0.039
	Tight/FixedCutTightCaloOnly	-0.397 ± 0.042	-0.238 ± 0.027	-0.168 ± 0.035	-0.061 ± 0.039
	Loose/FixedCutTight	-0.390 ± 0.044	-0.230 ± 0.027	-0.169 ± 0.036	-0.065 ± 0.039

Table 7.4: The double difference results in different WPs for end-cup unconverted photons