Studies on the background estimation for the measurement of $Z(\to \ell^+\ell^-)\gamma$ differential cross-sections

DESY summer school project

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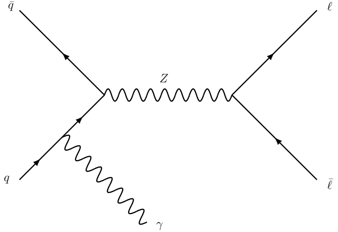
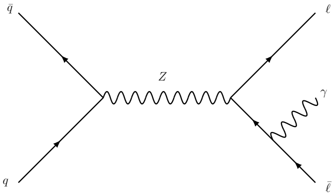
What is measured and why?

- Measurement of differential cross-sections of the process $Z(\rightarrow \ell^+\ell^-)\gamma$

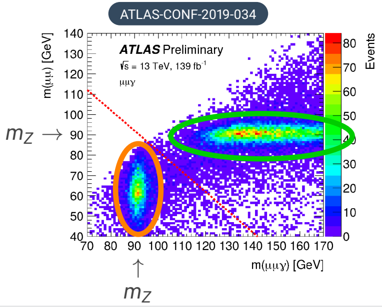
Initial State Radiation



Final State Radiation



- Use only ISR events
- Precision measurement
  $\rightarrow$ compare to theoretical predictions
- Also search for new physics (e.g. direct coupling of Z and γ)



What is measured and why?

- Precision measurement of

$$\sigma_{pp\to\ell\ell\gamma} = \frac{N_{\text{sig}}}{C \cdot \int \mathcal{L}\, dt} \tag{1}$$

with $C \triangleq$ factor for detector inefficiencies and resolution

$\rightarrow$ Need high precision in N_{sig}

- Events are selected $\rightarrow N_{\text{obs}}$
- Subtract number N_{bkg} of background events which pass the selection

$$N_{\text{sig}} = N_{\text{obs}} - N_{\text{bkg}} \tag{2}$$

$\rightarrow$ We need a good background estimation

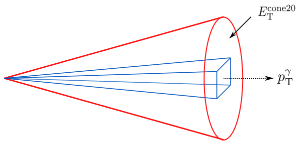
- **Dominant background:** Z**+jets** $\triangleq$ Z-boson and a jet which looks like a photon

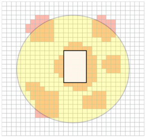
$\rightarrow$ We need to identify photons

Photon identification in a nutshell

Isolation

- Scalar sum of transverse energy within a cone of size $\Delta R = 0.2$
- Subtract the contributions close to the photon





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→ isolated: $E_{\mathrm{T}}^{\mathrm{cone20}}/p_T^{\gamma} < 0.065$

Photon ID

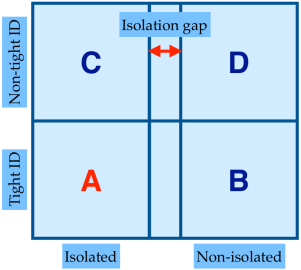
- Several cuts on variables describing the shower shape
  → Pass all requirements: "tight"
  → Fail "tight" but pass "looser" requirements: "non-tight"

photons: expected to be isolated with narrow shower shapes
jets faking photons: a lot of nearby activity ($E_{\mathrm{T}}^{\mathrm{cone20}}$) and broader shower shapes

How to estimate the Z+jets background?

2D sideband method

- Distribute the events in a 2D plane:
  - Photon ID: either tight or non-tight
  - Photon isolation: cut on $E_{\mathrm{T}}^{\mathrm{cone20}} - 0.065\, p_T^{\gamma}$
- Signal region A: isolated + tight photons
- Region A: dominated by signal
- Region B, C, D: dominated by Z+jets background



- **Idea**: estimate background events in A using the numbers of background events in B, C and D

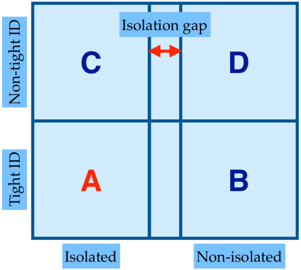
How to estimate the Z+jets background?

2D sideband method

- Assumption: photon ID and photon isolation are uncorrelated

$$\frac{N_A^{\text{Z+jets}}}{N_C^{\text{Z+jets}}} = \frac{N_B^{\text{Z+jets}}}{N_D^{\text{Z+jets}}}$$

$$\rightarrow \quad \text{correlation } R = \frac{N_A^{\text{Z+jets}} \cdot N_D^{\text{Z+jets}}}{N_B^{\text{Z+jets}} \cdot N_C^{\text{Z+jets}}}$$



$$N_A^{\text{Z+jets}} = R \cdot \frac{N_B^{\text{Z+jets}} \cdot N_C^{\text{Z+jets}}}{N_D^{\text{Z+jets}}} = R \cdot \frac{\left(N_B - c_B \cdot N_A^{\text{sig}}\right) \cdot \left(N_C - c_C \cdot N_A^{\text{sig}}\right)}{\left(N_D - c_D \cdot N_A^{\text{sig}}\right)}$$

with c_X = signal leakage factor in region X

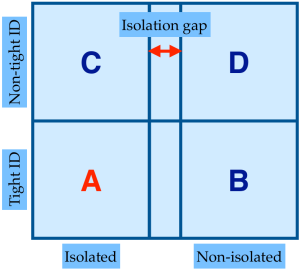
$\rightarrow$ R takes corrections due to correlation of photon ID and isolation into account (if there is no correlation, R is equal to 1)

How to estimate the Z+jets background?

2D sideband method - application

- Use MC to get good estimates for the correlation R and the signal leakage factors c_B, c_C and c_D
- Use the number of events N_B, N_C, N_D observed in data

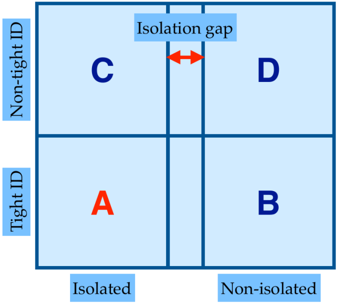
→ **Data-driven background estimate**



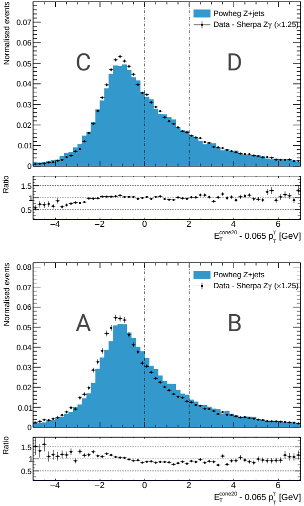
- R and c_X are estimated inclusively
  → Should they be calculated separately for different areas in phase space?
  → Investigate these parameters in more detail

How to estimate the Z+jets background?

What does this ABCD plane look like?

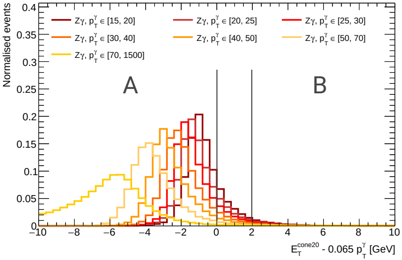


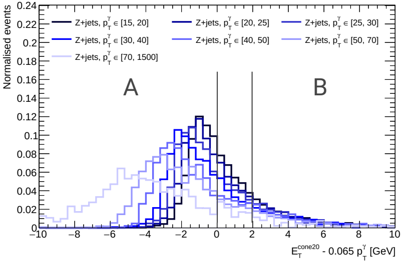
$\rightarrow$



Closer look at the isolation distribution

Isolation distribution in A+B (tight) for different p_T^γ ranges in MC

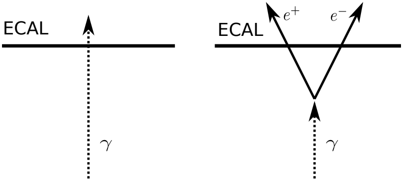




Difficulties and questions

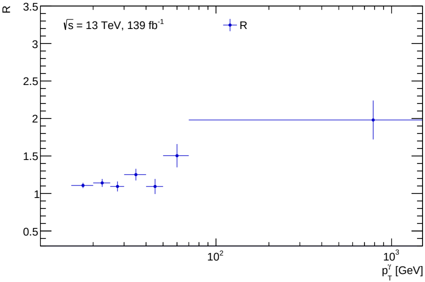
- Are photon ID and isolation correlated?
- Does the correlation R depend on characteristic variables like p_T^γ or η_γ?
- Do unconverted and converted photons behave the same way?

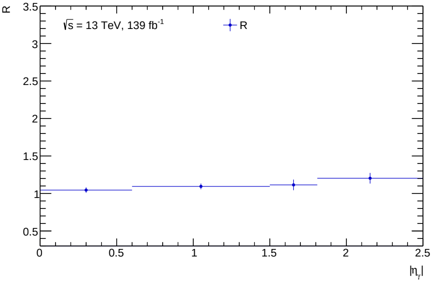
unconverted



converted

Correlation as a function of p_T^γ and η_γ





Reminder: $R = 1$ means there is no correlation

- R seems to be pretty constant as a function of η_γ
- R is getting larger for higher p_T^γ

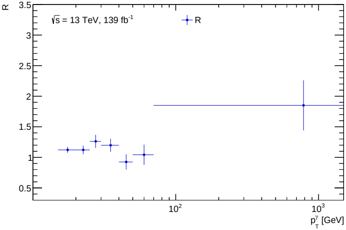
$\rightarrow$ Is this the same for converted / unconverted photons?

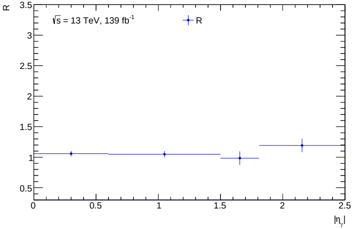
Correlation as a function of p_T^γ and η_γ

p_T^γ dependence

η_γ dependence

unconverted





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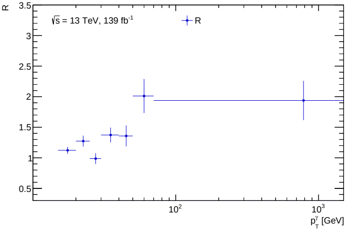
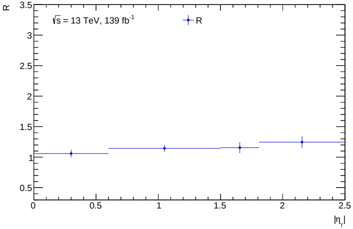


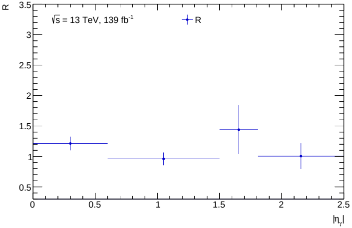


- p_T^γ dependence in R seems to get larger for converted photons
- R seems to be stable with η_γ

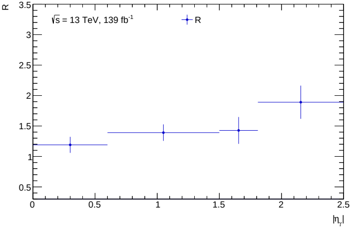
η_γ dependence of correlation R for $p_T^\gamma > 30$ GeV

What happens if we take only high-p_T^γ events?

unconverted



converted

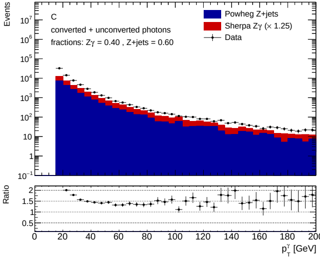


- η_γ fluctuations larger than without p_T^γ cut
- Correlation seems to increase with η_γ for converted photons

$\rightarrow$ Converted + high p_T^γ + high η_γ seems to be most problematic

p_T^{γ} distribution: MC vs data

C



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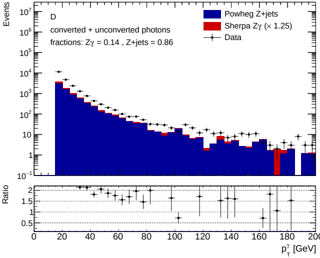
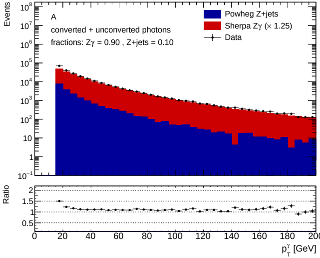


A



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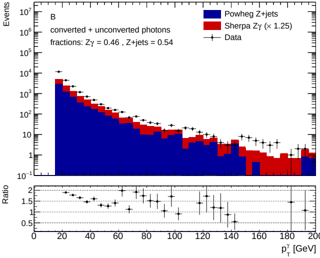


Conclusion

What do we learn from these studies?

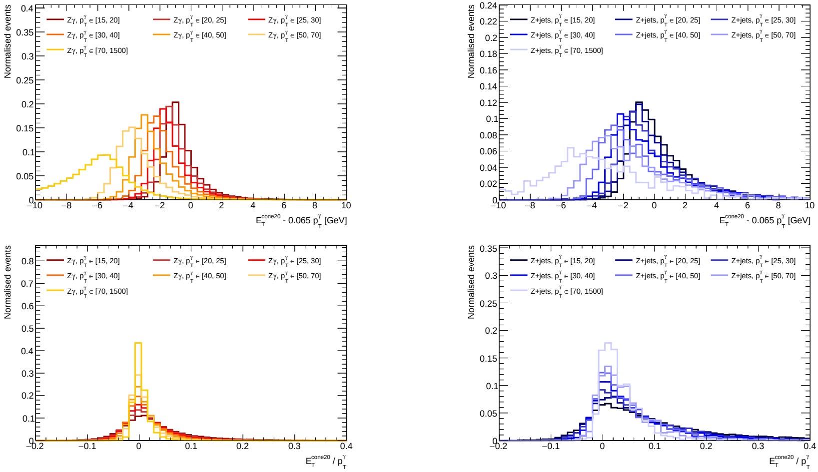
- The correlation seems to be sensitive to p_T^{γ} and also η_{γ} + conversion type
  - $\rightarrow$ We know where in phase space the problematic events are
  - $\rightarrow$ Maybe perform the background estimation in p_T^{γ}-η_{γ}-bins
- We see a p_T^{γ} dependence in R
  - $\rightarrow$ Wrong modelling of p_T^{γ} could bias our estimation
  - $\rightarrow$ Have a closer look at the p_T^{γ} distribution

Next steps

- Investigate the photon ID in more detail
  - $\rightarrow$ Having a look at the effect each variable has
- Perform an estimation with p_T^{γ}-binned R and c_X
  - $\rightarrow$ See how it compares to the estimation with inclusive R

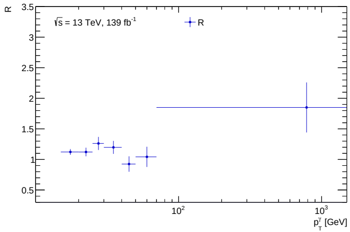
Backup

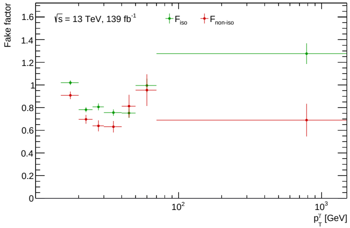
Isolation distribution in A+B (tight) for different p_T^γ ranges



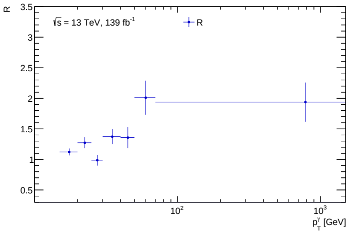
p_T^γ dependence with E_T^{cone20}, LoosePrime4

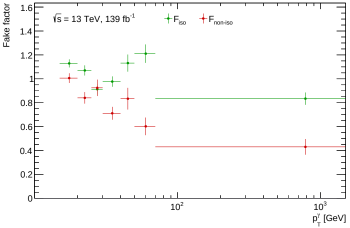
unconverted





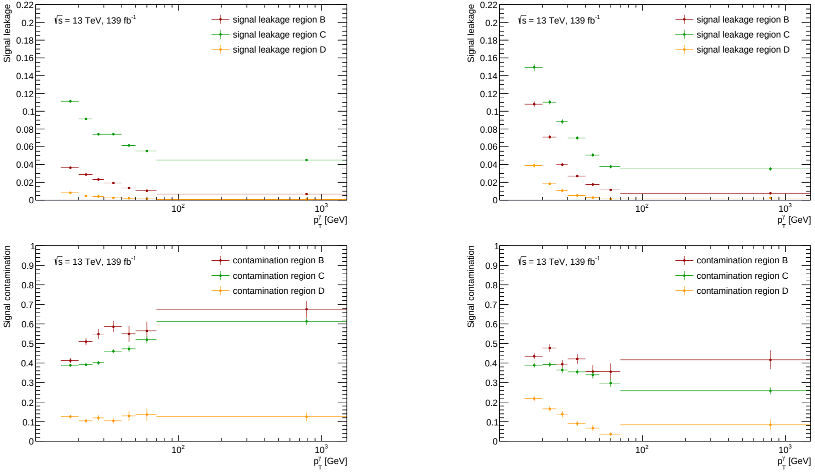
converted





p_T^γ dependence of signal leakage and contamination

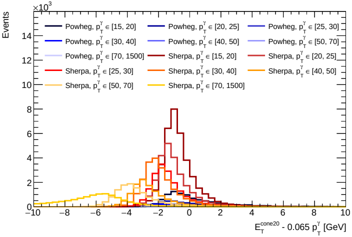
unconverted | converted

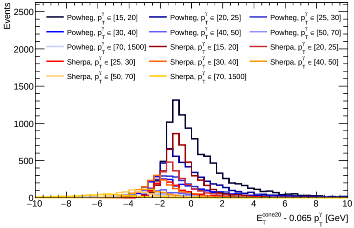


$E_T^{cone20} - 0.065 \cdot p_T^{\gamma}$ absolut distributions

tight (A+B) / non-tight (C+D)

unconverted





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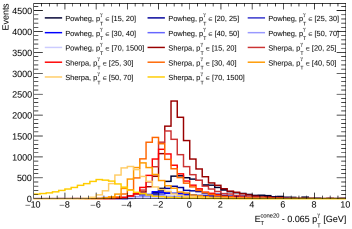
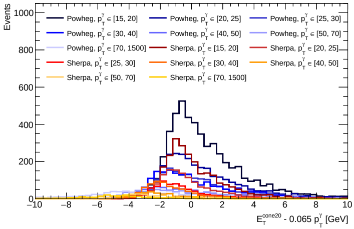
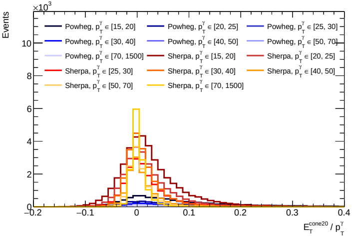


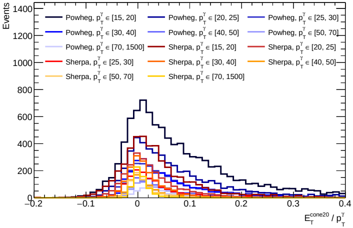


E_T^{cone20} / p_T^{γ} absolut distributions

tight (A+B) | non-tight (C+D)

unconverted





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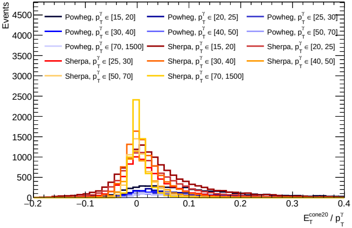
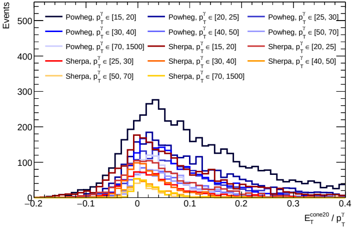
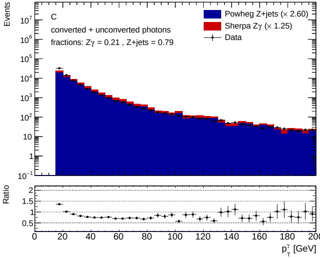




p_T^γ distribution: MC vs data with $k_{\text{Powheg}} = 2.6$

C



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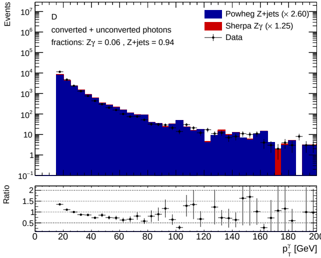
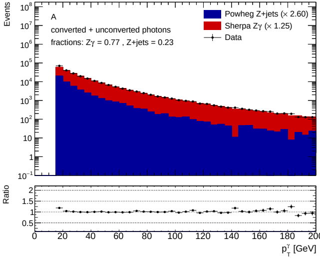


A



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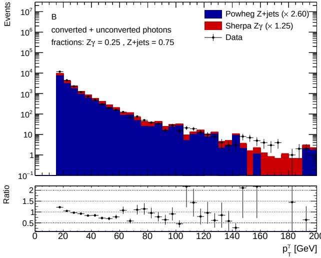
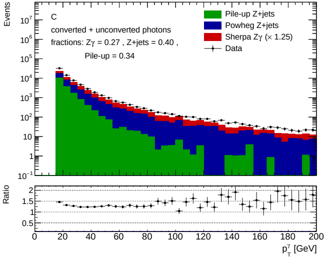


p_T^γ distribution: MC vs data with pile-up events

C



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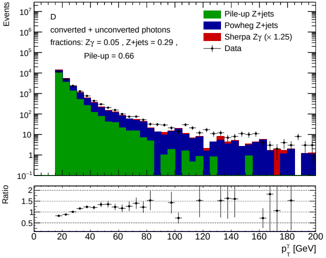
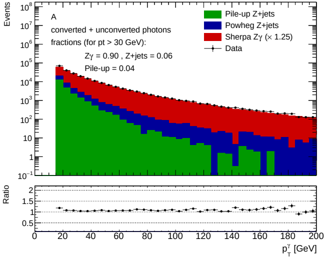


A



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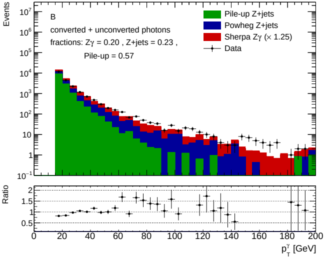
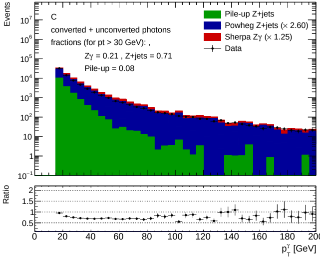
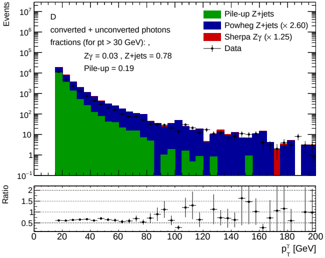


p_T^γ distribution: with $k_{\text{Powheg}} = 2.6$ and pile-up events

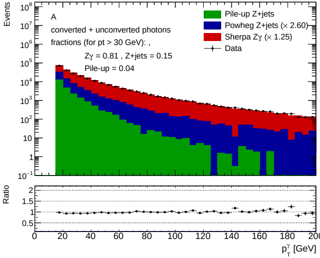
C

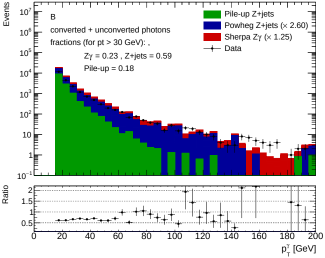




D

A





B

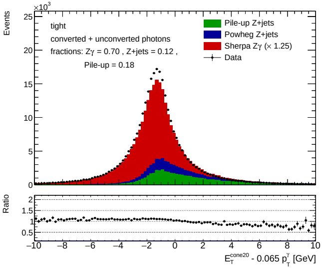
Event selection

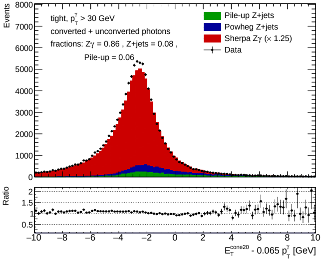
ATLAS-CONF-2019-034

	Photons	Electrons	Muons
Kinematics:	$E_{\mathrm{T}} > 30$ GeV	$p_{\mathrm{T}} > 30, 25$ GeV	$p_{\mathrm{T}} > 30, 25$ GeV
	$\|\eta\| < 2.37$	$\|\eta\| < 2.47$	$\|\eta\| < 2.5$
	excl. $1.37 < \|\eta\| < 1.52$	excl. $1.37 < \|\eta\| < 1.52$	
Identification:	Tight [53]	Medium [54]	Medium [52]
Isolation:	FixedCutLoose [53]	FCLoose [54]	FCLoose_FixedRad [52]
	$\Delta R(\ell, \gamma) > 0.4$	$\Delta R(\mu, e) > 0.2$	
Event selection:	$m(\ell\ell) > 40\,\mathrm{GeV}$, $m(\ell\ell) + m(\ell\ell\gamma) > 182\,\mathrm{GeV}$		

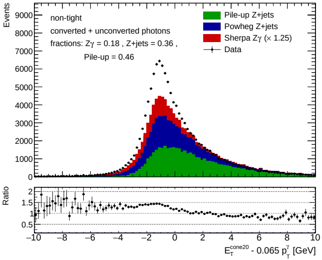
isolation distribution: MC vs data with pile up

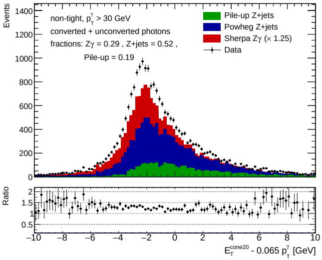
tight (A+B)





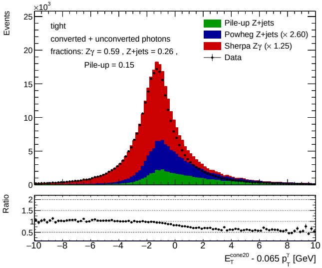
non-tight (C+D)

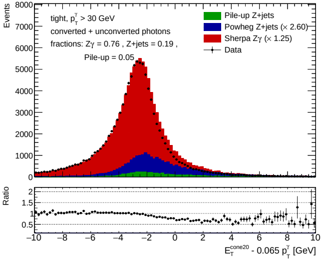




isolation distribution: MC vs data with pile up and $k_{\text{Powheg}} = 2.6$

tight (A+B)





non-tight (C+D)