



# Z+ $\mu$ studies with fake muons from light jets

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MAX-PLANCK-GESELLSCHAFT

# Data and MC Samples

## Data (p2425):

- Period D – G
- Integrated Luminosity:  $1.03 \text{ fb}^{-1}$
- GRL:  
data15\_13TeV.periodAllYear\_DetStatus-v67-pro19-02\_  
DQDefects-00-01-02\_PHYS\_StandardGRL\_All\_Good.xml

## Luminosity calculation and pileup reweighting:

- ilumicalc\_histograms\_None\_276262-280614.root

## Monte Carlo Simulation (p2419):

- Z+jets (Sherpa, 361372-361419)
- tt (Powheg/Pythia, 410000)
- WZ (Powheg/Pythia8, 361601)
- qq→ZZ (Powheg/Pythia8, 361603)
- gg→ZZ (Sherpa, 361073)

# Event Selection

- Following the guidelines on the HZZIIIIPreparationRunII2014 Twiki, AnalysisBase 2.3.29.

## Z → ee and Z → μμ candidates:

- Nominal lepton identification criteria, isolation and IP-cuts applied.
- $p_{T1} > 20$  GeV,  $p_{T2} > 15$  GeV.
- $|m_{ll} - M_Z^{\text{PDG}}| < 15$  GeV

## Additional muons:

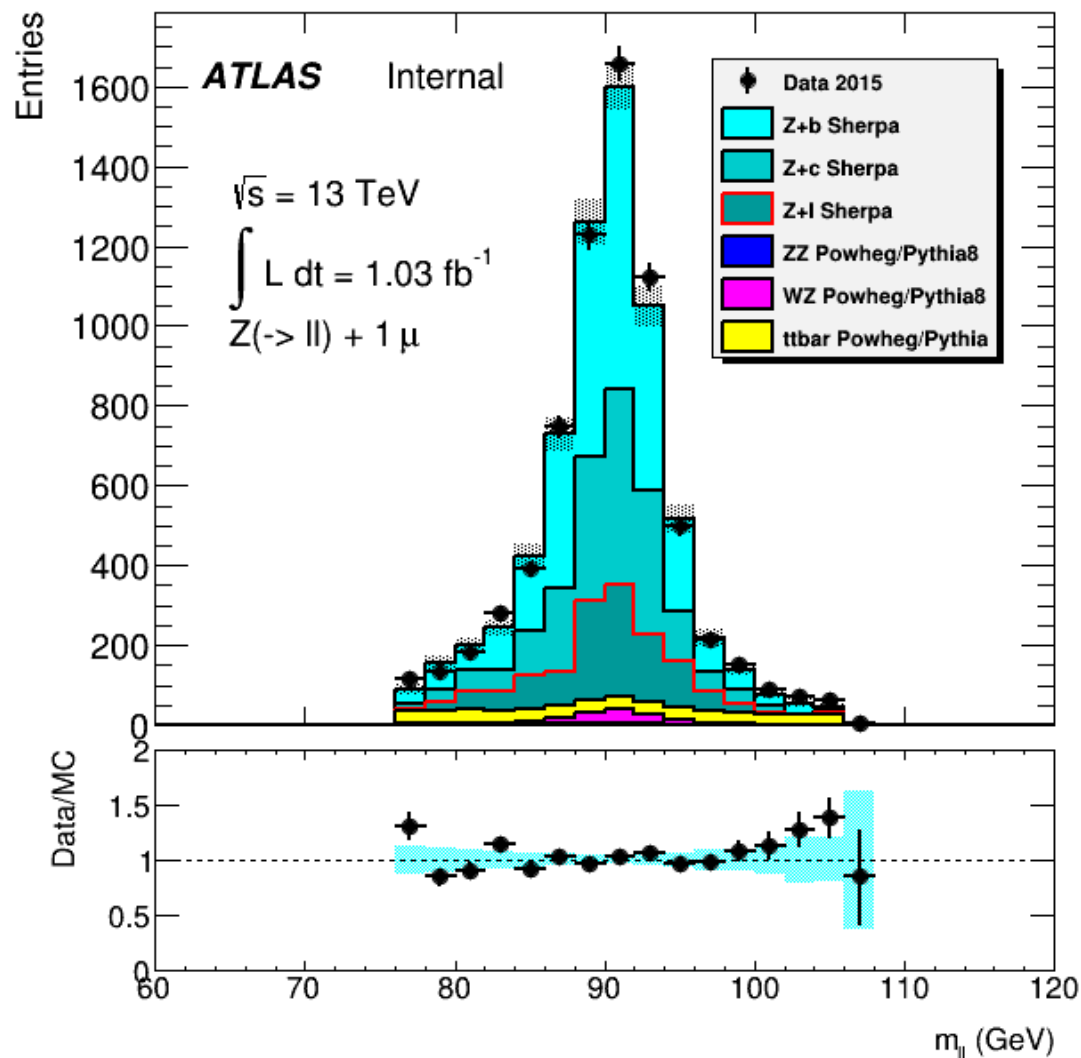
- Exactly one additional combined muon,  $p_T > 6$  GeV.
- No cut on impact parameter significance, no isolation criteria.
- J/Ψ veto applied on Z(→μμ)+μ candidates.
- **Enrichment with Z+light jet events:**  
by means of the cut on the momentum balance,  $(p_{T,\text{ID}} - p_{T,\text{MS}}) / p_{T,\text{ID}}$

# Cross check: Z boson candidates

Z+ $\mu$  candidates before the cut on the  $p_T$ -balance:

Number of expected and observed events

Data	6949
Total MC	$6803 \pm 124$
Z + l jets	$1163 \pm 77$
Z + c jets	$1944 \pm 66$
Z + b jets	$3081 \pm 71$
Top Quark	$440 \pm 9$
WZ	$148 \pm 2$
ZZ	$27.0 \pm 0.4$

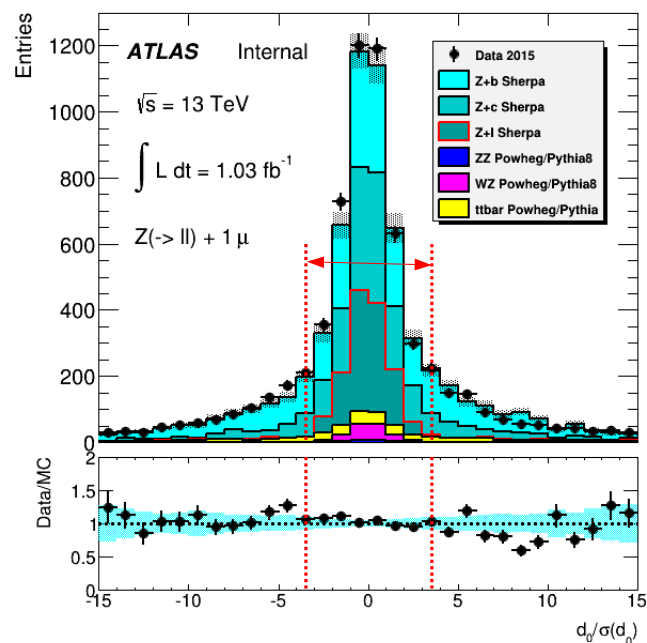


Reasonable agreement between data and simulation.

# IP and isolation for additional muons

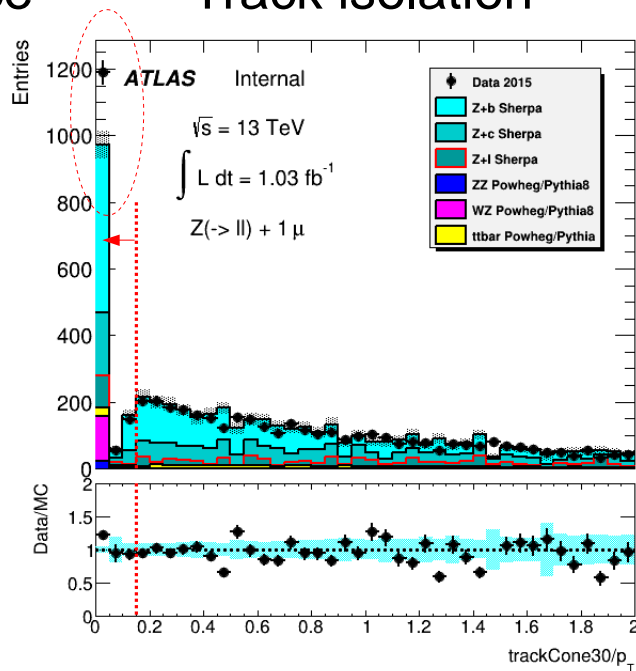
Z+ $\mu$  candidates before the cut on the  $p_T$ -balance:

Impact parameter significance



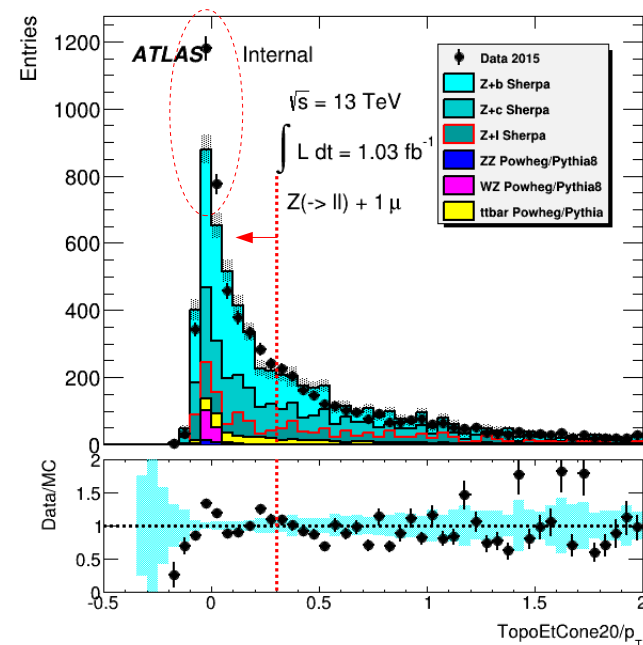
Good agreement  
between MC and data.

Track isolation



MC underestimated  
at low isolation values.

Calorimeter isolation



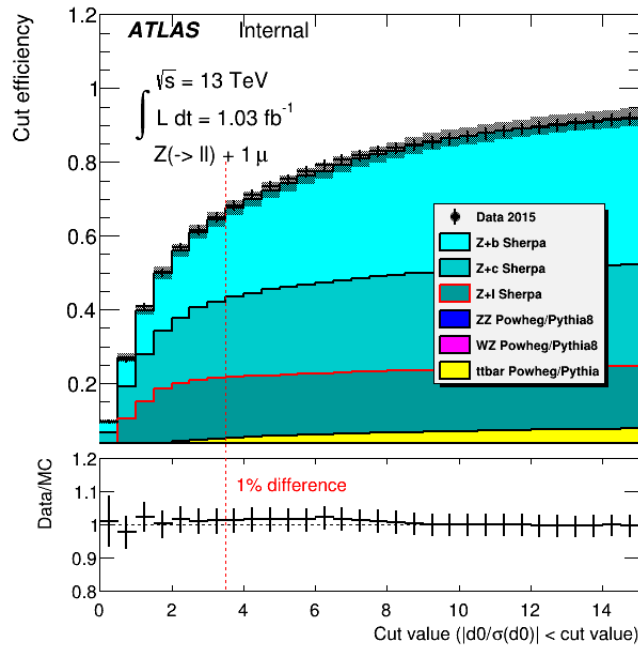
MC underestimated  
around isolation=0.

MC-data discrepancies, similar to those already reported by other groups.

# IP and isolation cut efficiencies

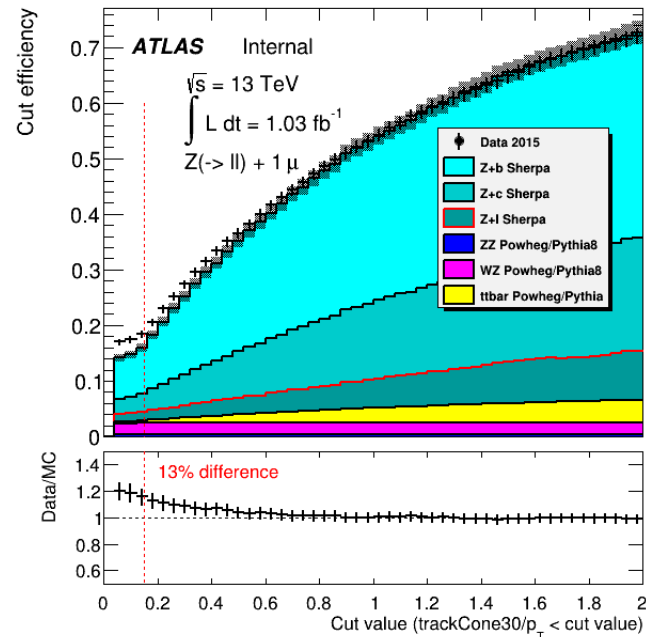
Z+ $\mu$  candidates before the cut on the  $p_T$ -balance:

Impact parameter significance



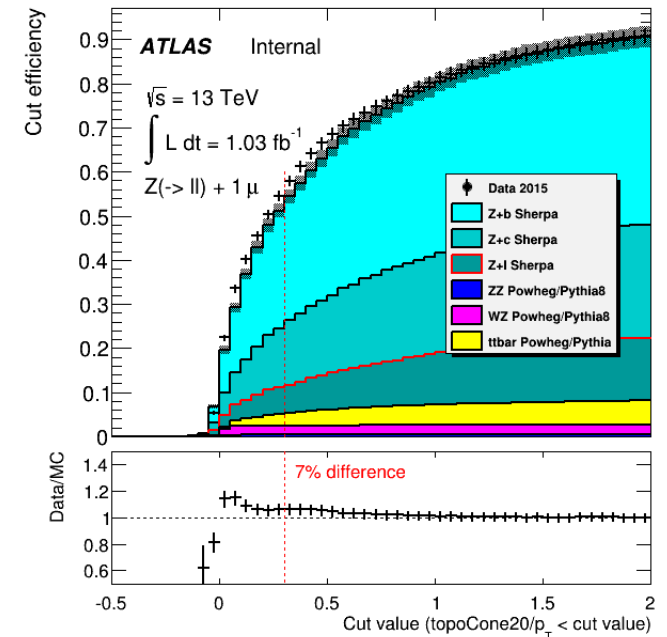
Good agreement between MC and data.

Track isolation



MC underestimated at low isolation values.

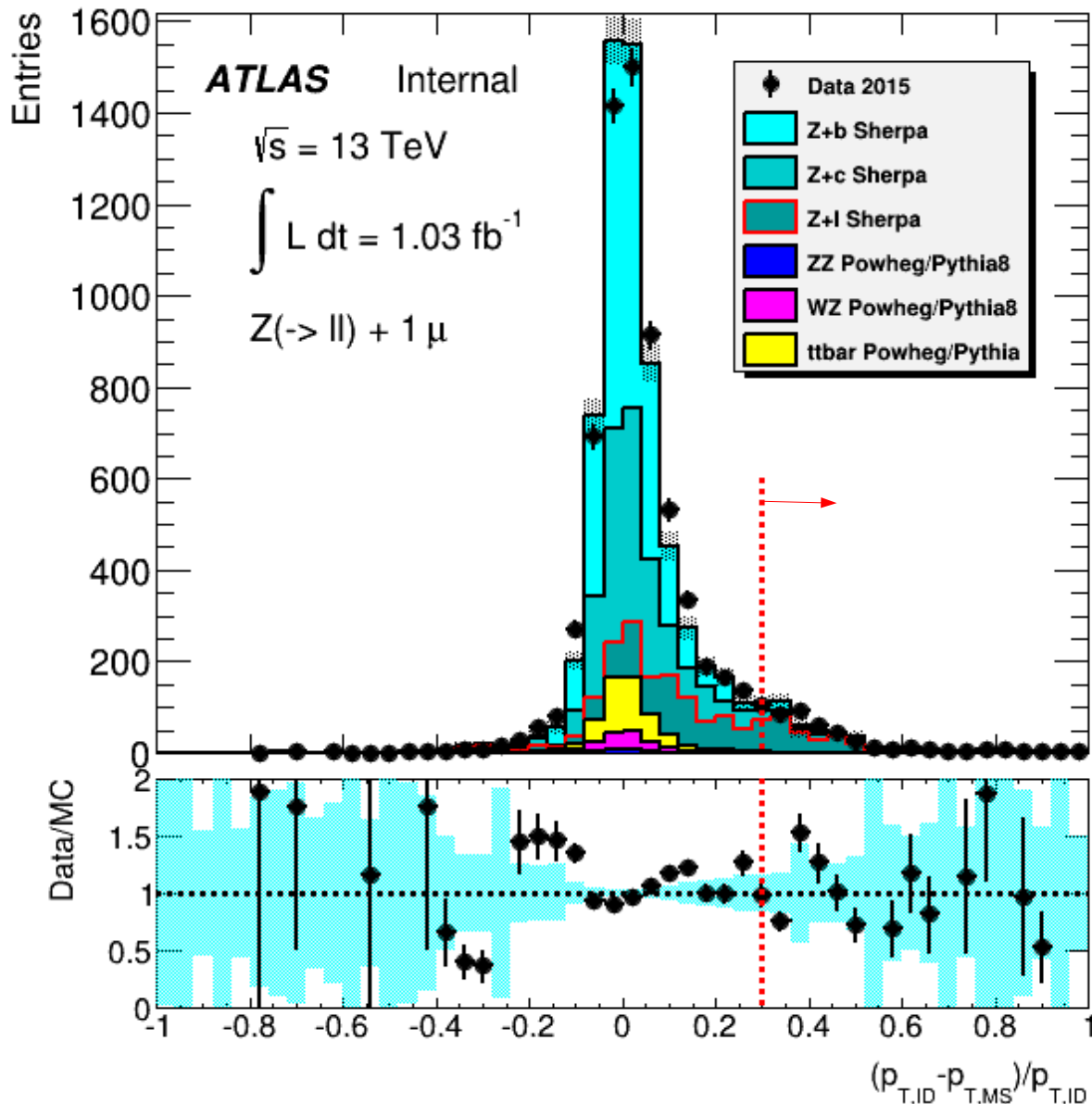
Calorimeter isolation



MC underestimated around isolation=0.

MC-data discrepancies, similar to those already reported by other groups. Cut efficiencies agree with those reported by other groups.

# Momentum balance distribution



Applying cut on pT-balance in order to increase the Z+light jet contribution:

$$(p_{T,ID} - p_{T,MS})/p_{T,ID} > 0.3$$

- Cut value chosen such to give the highest ratio between Z+light jet and other backgrounds.

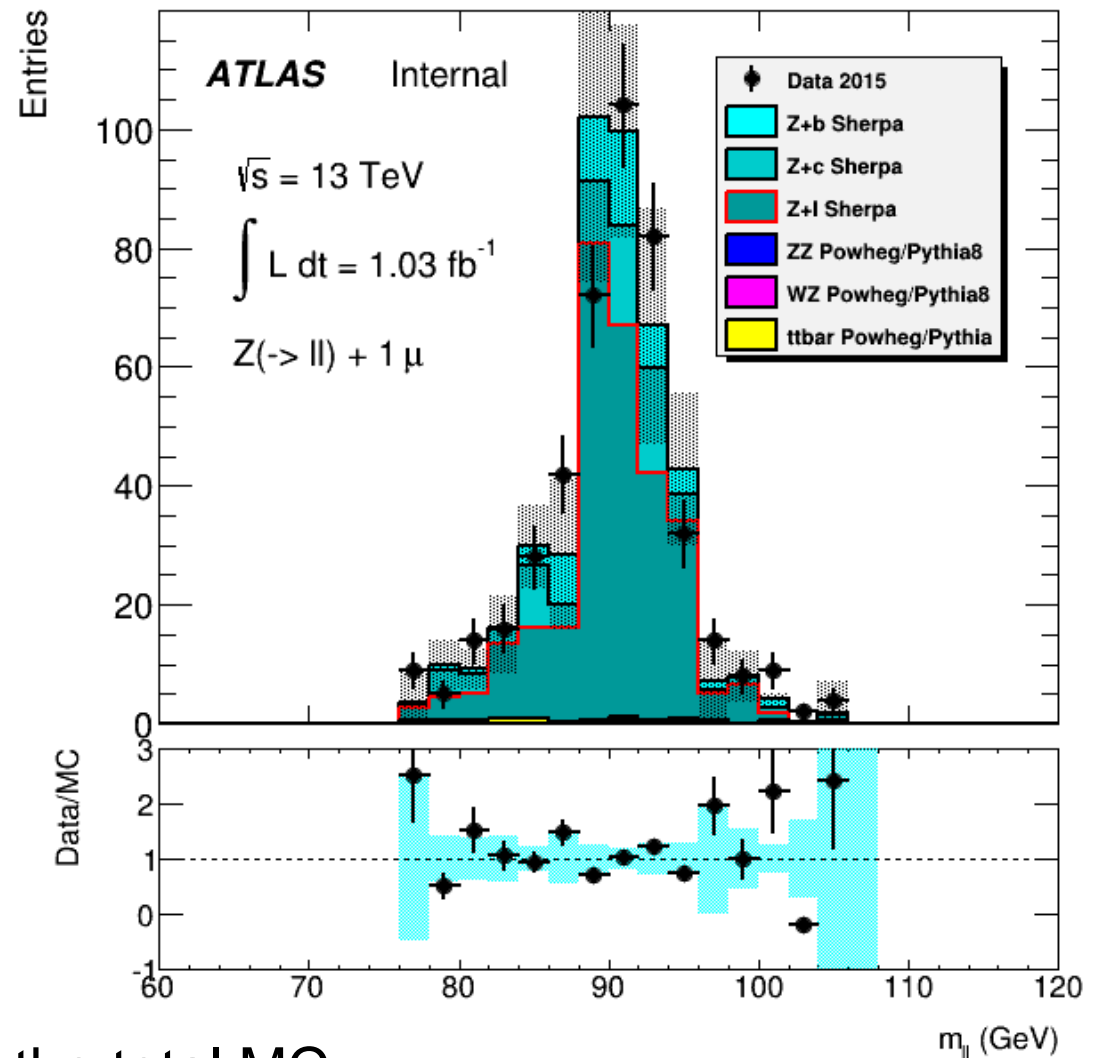
Reasonable agreement between data and simulation.

# Cross check (II): Z boson candidates

Z+ $\mu$  candidates after the cut on the  $p_T$ -balance  $> 0.3$ :

Number of expected and observed events

Data	441
Total MC	$418 \pm 46$
Z + light jets	$274 \pm 43$
Z + c-jets	$81 \pm 15$
Z + b-jets	$54 \pm 9$
Top Quark	$7 \pm 1$
WZ	$1.7 \pm 0.2$
ZZ	$0.24 \pm 0.04$



Z+light jets comprise 66% of the total MC.

Good agreement between data and simulation, rather low statistics.



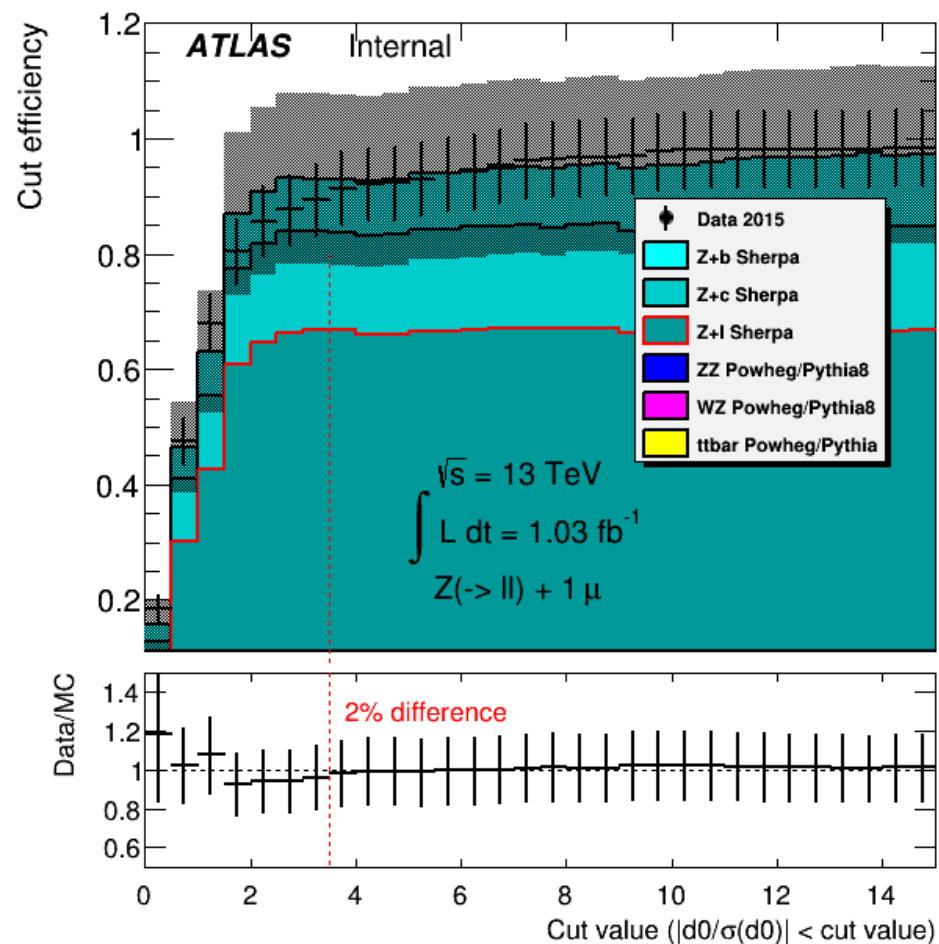
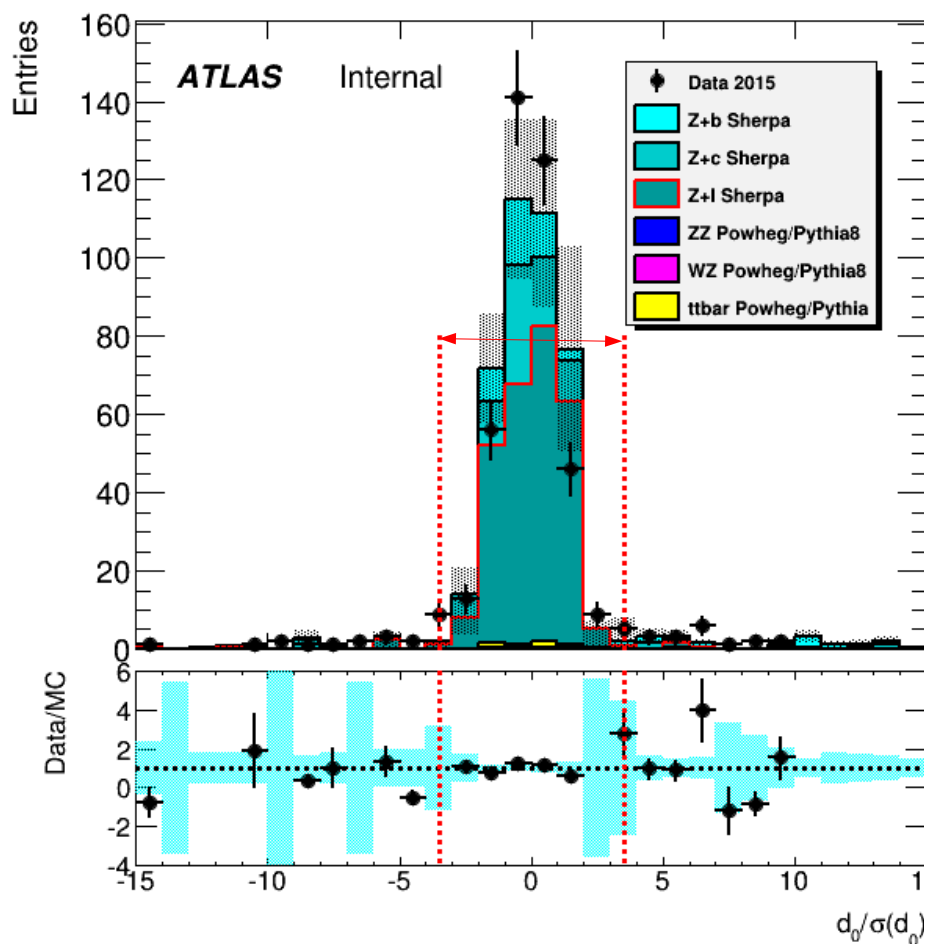
# IP and isolation cuts on an additional muon

Only additional  $\mu$  candidates after the cut on the  $p_T$ -balance  $> 0.3$ :

	All Z+ $\mu$ Candidates (after $p_T$ - balance)	Only TopoC20/ $p_T$ <0.3	Only TrackC30/ $p_T$ <0.15	Only  d0sig  <3.5	All cuts
Data	441	71 (0.16)	224 (0.51)	398 (0.90)	47 (0.11)
Total MC	$418 \pm 46$	$32 \pm 11$ ( $0.08 \pm 0.03$ )	$148 \pm 28$ ( $0.35 \pm 0.08$ )	$388 \pm 45$ ( $0.93 \pm 0.15$ )	$25 \pm 10$ ( $0.06 \pm 0.02$ )
Z + light jets	$274 \pm 43$	$11 \pm 10$	$91 \pm 25$	$273 \pm 42$	$11 \pm 9$
Z + c-jets	$81 \pm 15$	$11 \pm 5$	$28 \pm 10$	$70 \pm 14$	$5 \pm 4$
Z + b-jets	$54 \pm 9$	$8 \pm 3$	$26 \pm 6$	$38 \pm 8$	$7 \pm 3$
Top Quark	$7 \pm 1$	$0.6 \pm 0.3$	$1.1 \pm 0.4$	$4.8 \pm 0.9$	$0.08 \pm 0.06$
WZ	$1.7 \pm 0.2$	$1.4 \pm 0.2$	$1.6 \pm 0.2$	$1.6 \pm 0.2$	$1.4 \pm 0.2$
ZZ	$0.24 \pm 0.04$	$0.19 \pm 0.04$	$0.22 \pm 0.04$	$0.23 \pm 0.04$	$0.18 \pm 0.03$

# Impact parameter significance

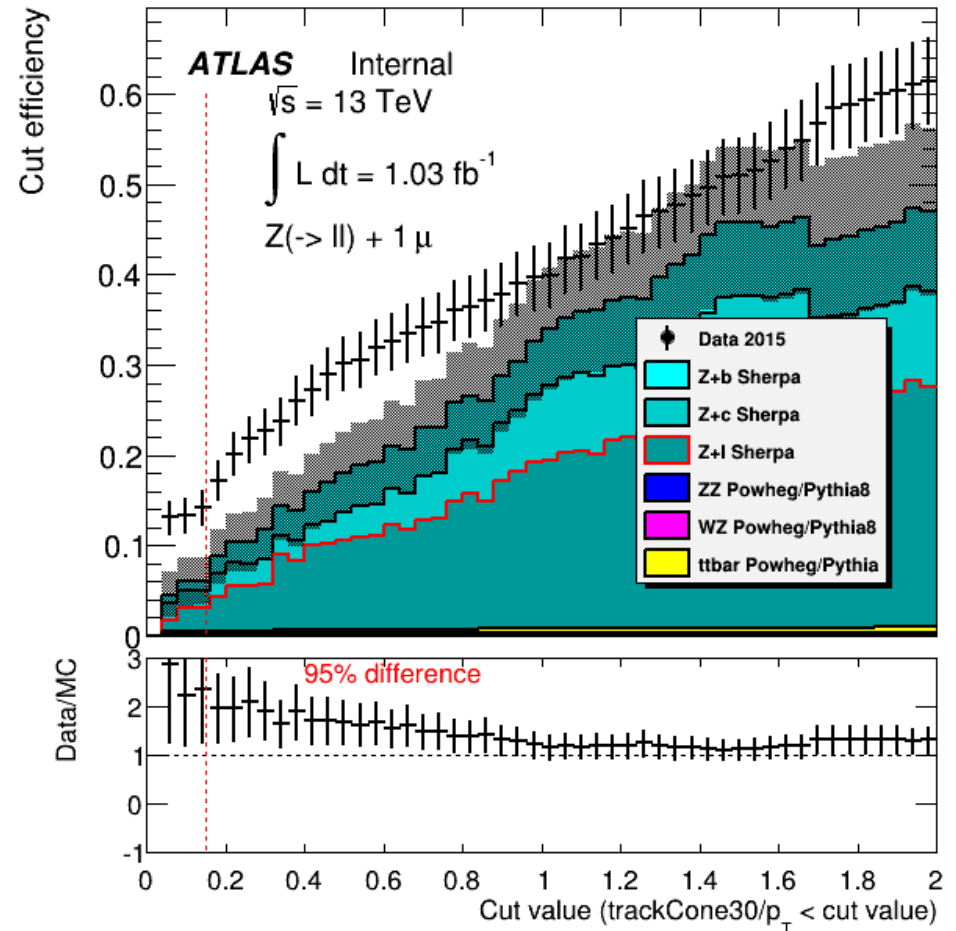
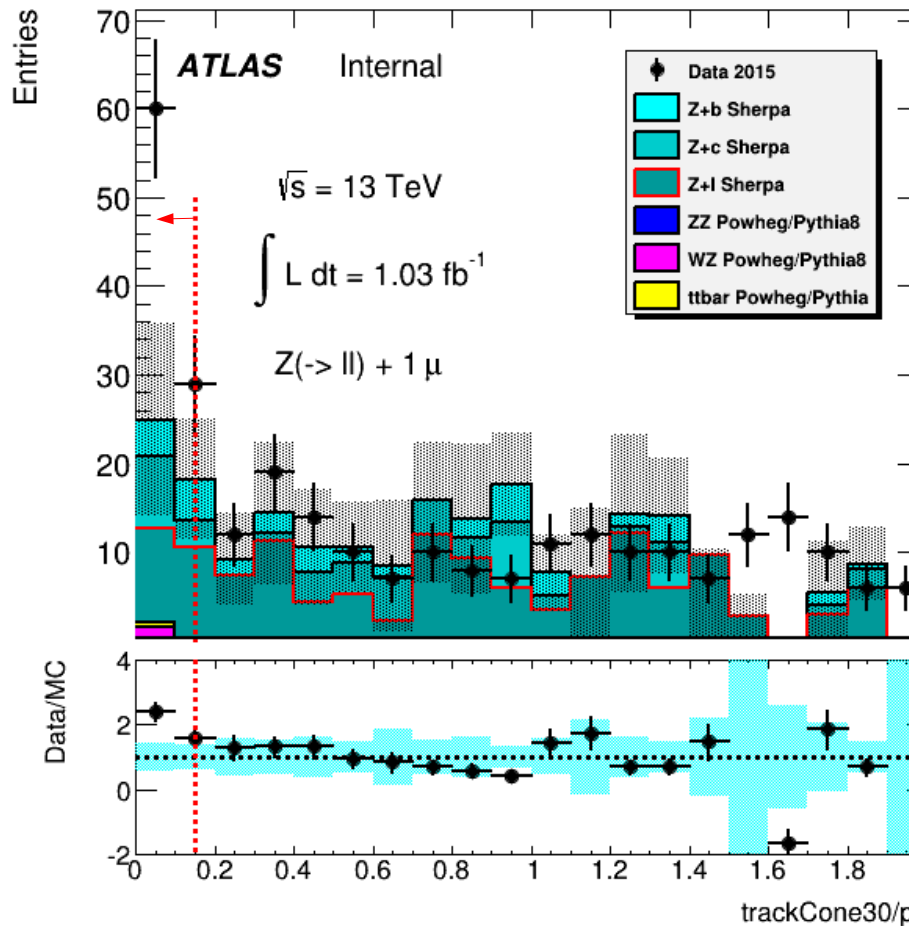
Additional  $\mu$  candidates after the cut on the  $p_T$ -balance  $> 0.3$ :



Good agreement between data and simulation, poor MC statistics.

# Track isolation

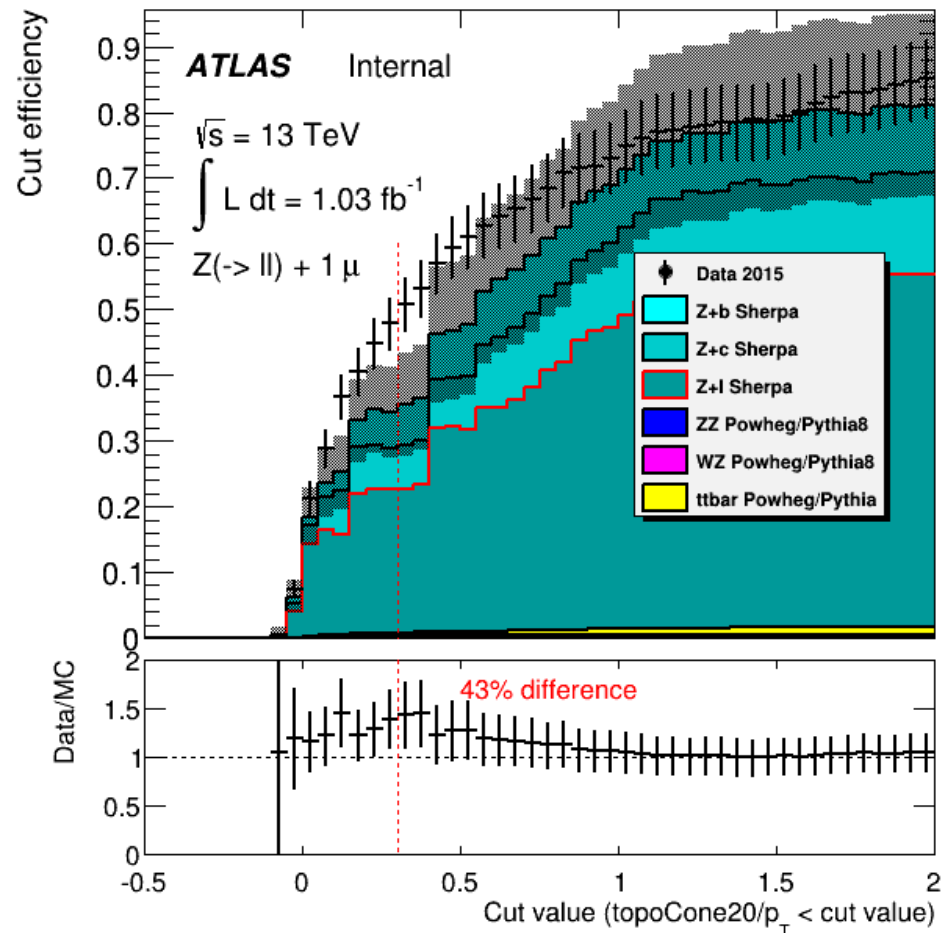
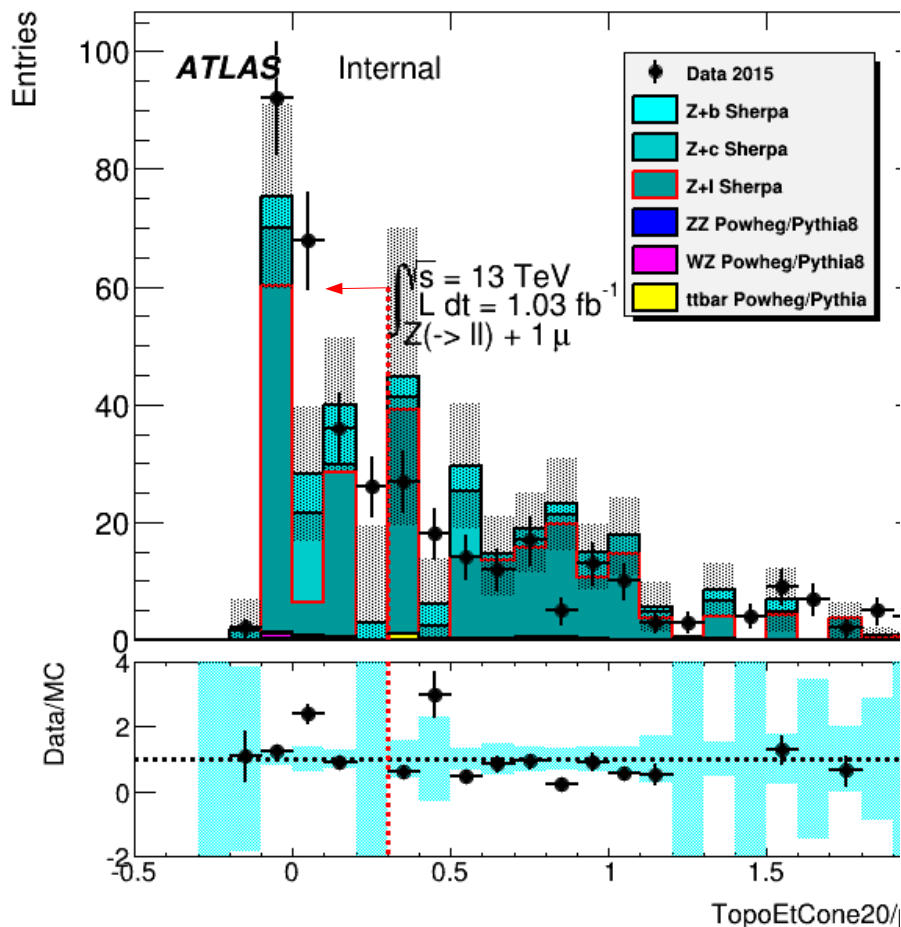
Additional  $\mu$  candidates after the cut on the  $p_T$ -balance  $> 0.3$ :



Efficiency in data larger by a factor of  $\sim$ two at the nominal cut value of 0.15 .  
 $\Rightarrow$  Corresponds to  $\sim 2\sigma$ , poor MC statistics.

# Calorimeter isolation

Additional  $\mu$  candidates after the cut on the  $p_T$ -balance  $> 0.3$ :



Efficiency in data larger by a factor of  $\sim 1.5$  at the nominal cut value of 0.3 .  
 $\Rightarrow$  Corresponds to  $\sim 2\sigma$ , poor MC statistics.

# Summary

- **Transverse momentum balance** of the combined muons in  $Z+\mu$  events used as a handle **to enhance** the relative **contribution from  $\pi/K$ -muons** (from original 17% to 66%).
- Efficiency of the impact parameter significance and isolation cuts on muons studied in these enriched samples.
- **Discrepancy between data and MC** observed in distributions of **isolation variables**.  
Similar behaviour as in samples without the  $p_T$ -balance cut.
- Measurement **limited by the low data and MC statistics**.  
=> Next: increase data statistics to  $2 \text{ fb}^{-1}$  with latest GRLs.  
=> Next: analyse the mc15b as soon as available.