Measurements of $Z\gamma$ + jets differential cross sections in pp collisions at $\sqrt{s} = 13 TeV$ with the ATLAS detector

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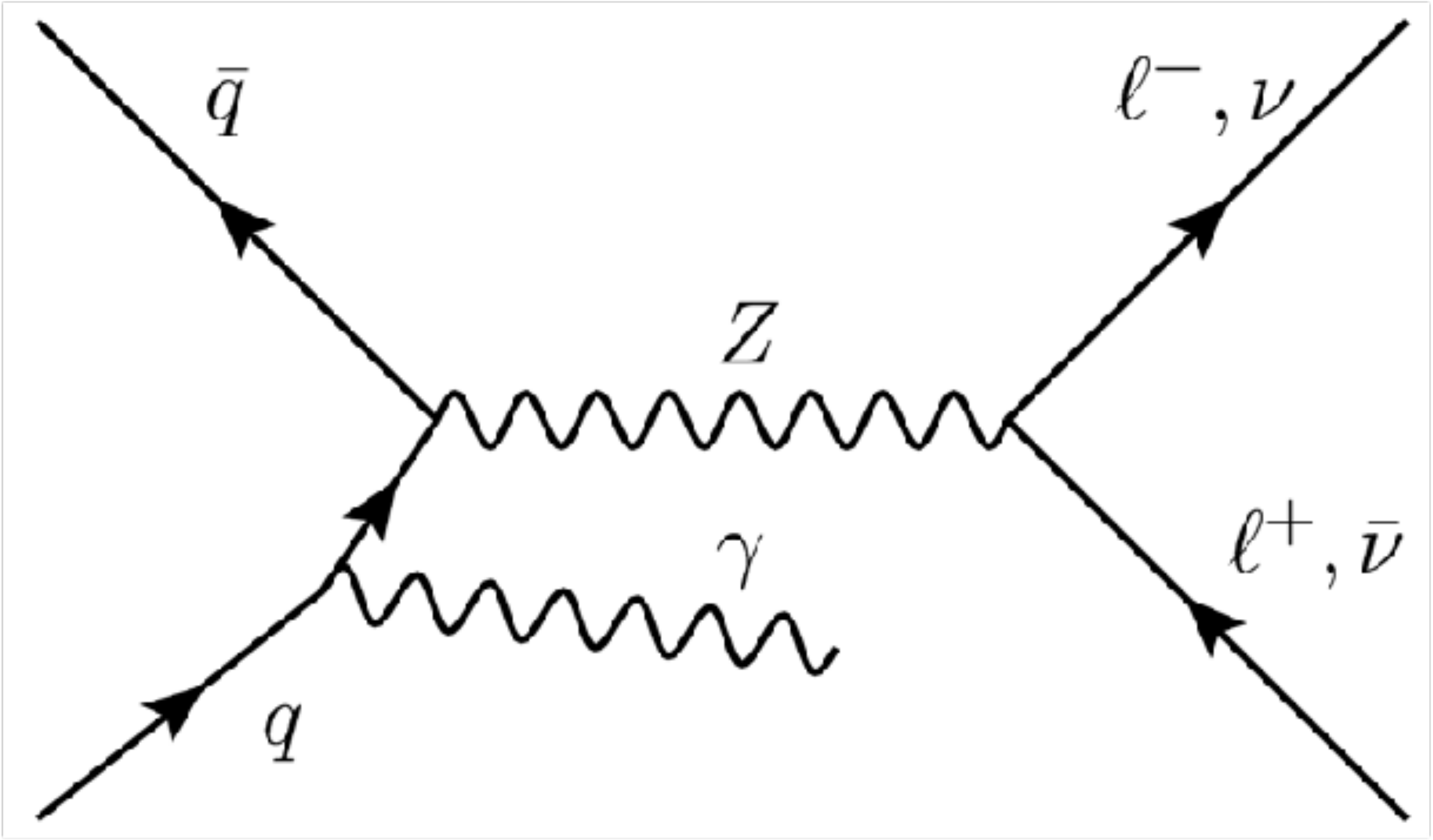
Introduction

◉ Motivations:

- $Z\gamma$ production in association with hadronic jets
  - large data statistics with small background
  - be sensitive to QCD
  - search for physics beyond the SM, like EFT
  - Z-boson polarisation measurement
- The **Differential distributions can be used for**
  - constraining parameters of the SM Lagrangian
  - validating parton density function (PDF)
  - constraining the Monte Carlo (MC) models
- Dedicated study of the jet activity for the first time



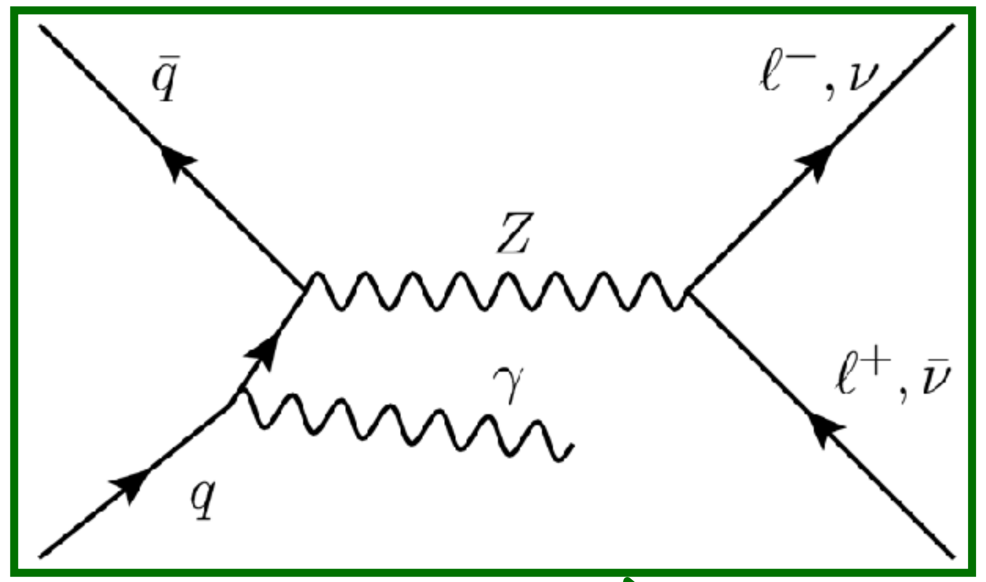
$Z\gamma$ production via initial state radiation (ISR) process

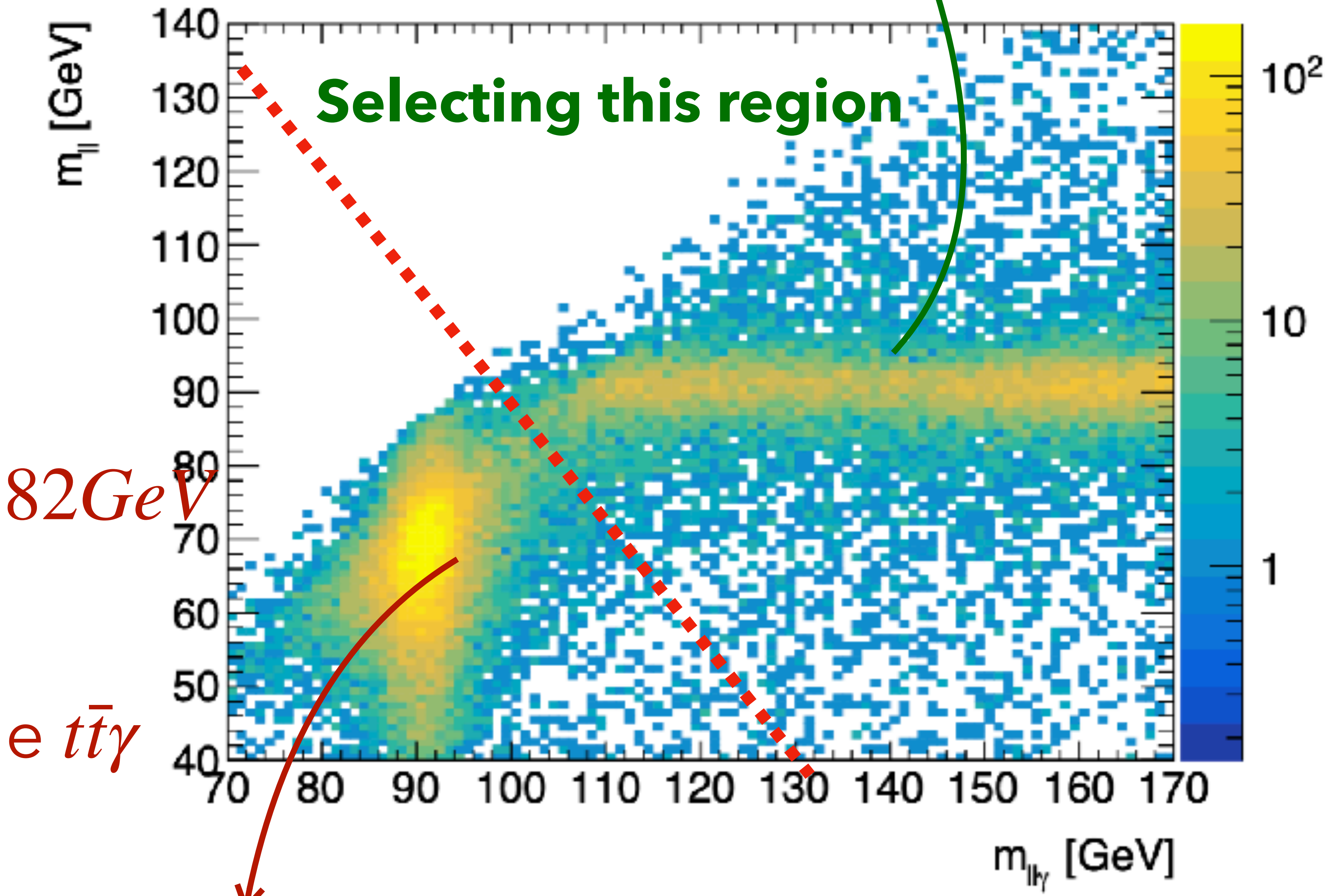
Event Selection

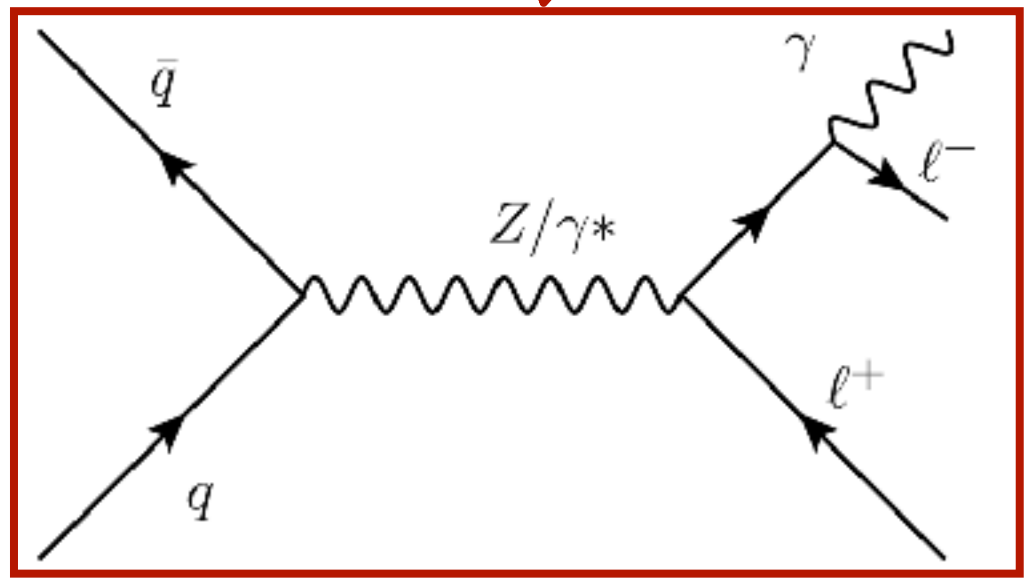
Observable	Signal Region	Control Region
Number of signal leptons	2 Opposite Sign, Same Flavour	2 Opposite Sign, Different Flavour
Lepton	$p_{\mathrm{T}}(\ell_1) > 30$ GeV, $p_{\mathrm{T}}(\ell_2) > 25$ GeV	
Photon	≥ 1 photon with $p_{\mathrm{T}}^{\gamma} > 30$ GeV	
$m_{\ell\ell}$	> 40 GeV	
$m_{\ell\ell} + m_{\ell\ell\gamma}$	> 182 GeV	

- $m_{\ell\ell} > 40GeV$ is required to avoid low-mass resonances, e.g. $\gamma *$
- Final state radiation (FSR) events are reduced by requiring $m_{\ell\ell} + m_{\ell\ell\gamma} > 182GeV$
- Candidate events must pass single lepton trigger
- Control region (CR) in $e\mu\gamma$ channel is defined to check the modelling of the $t\bar{t}\gamma$ background.

ISR process dominated



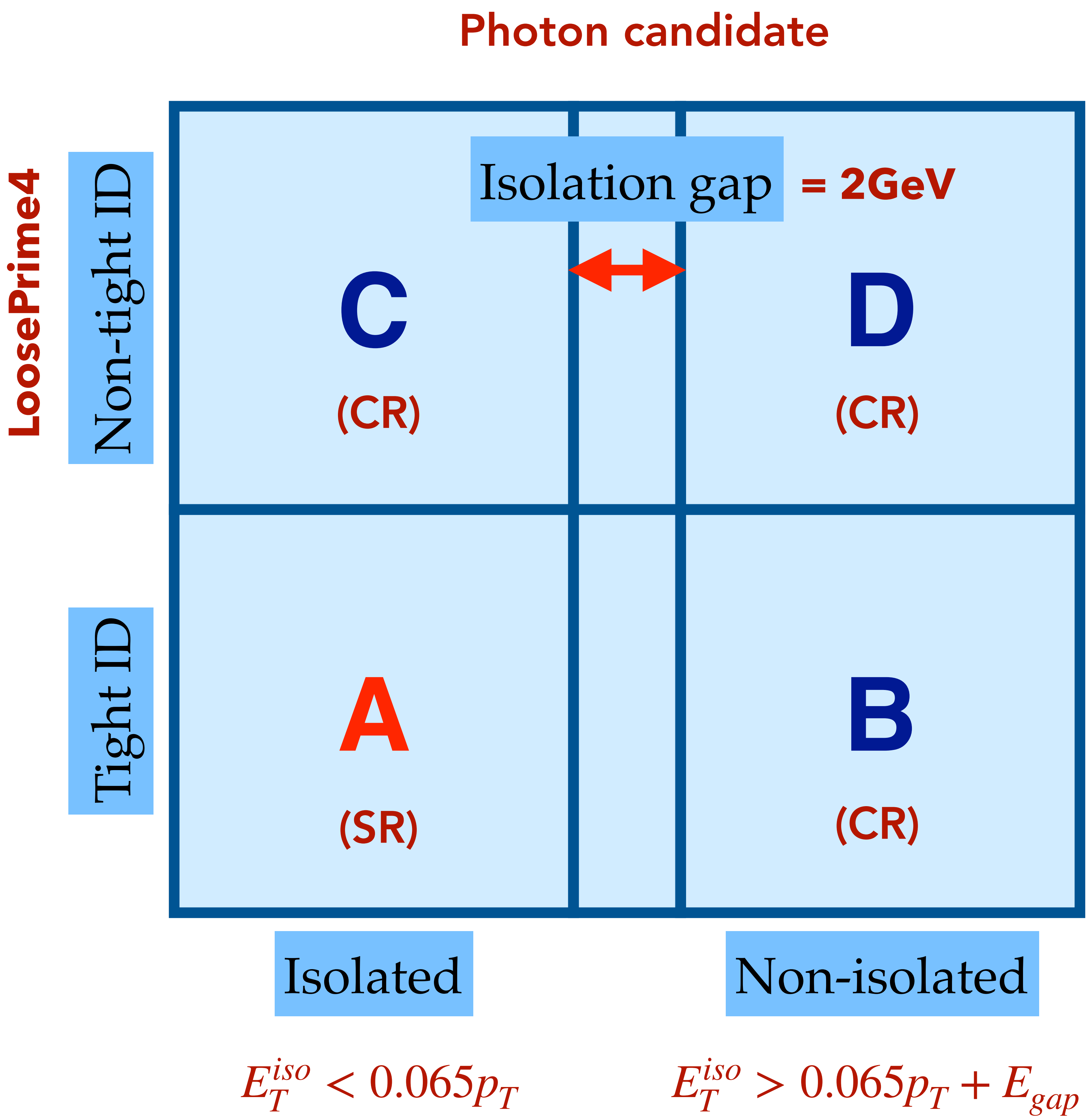




FSR process dominated

Background estimation — Z+jets

- Z+jets background



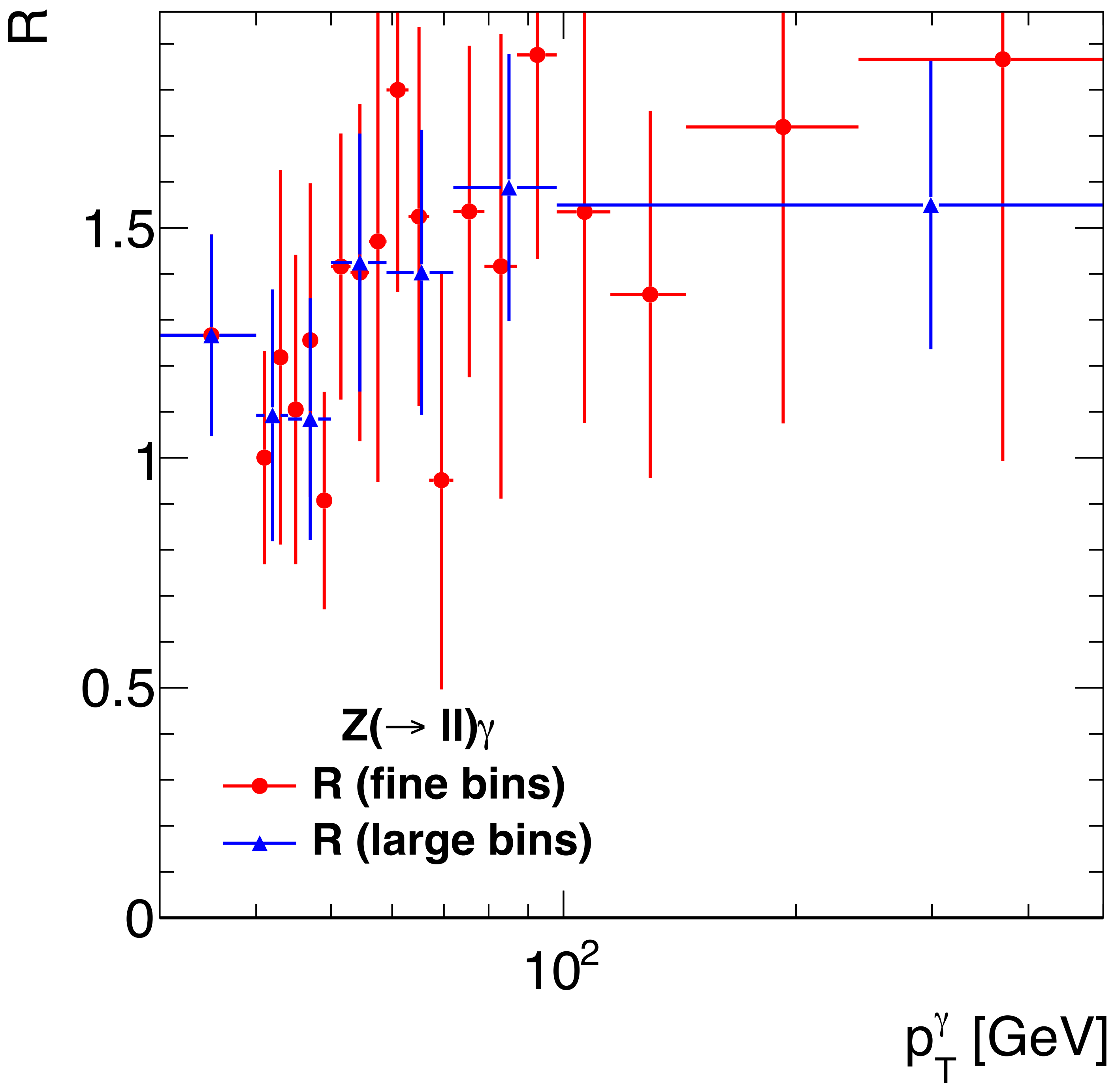
- One of the jets is misidentified as a photon
- 2D sideband method
- Correlation factor: $R = \dfrac{N_A^{Z+jets} \times N_D^{Z+jets}}{N_B^{Z+jets} \times N_C^{Z+jets}}$
- Signal leakage parameters: $c_B = \dfrac{N_B^{sig}}{N_A^{sig}}, c_C = \dfrac{N_C^{sig}}{N_A^{sig}}, c_D = \dfrac{N_D^{sig}}{N_A^{sig}}$
- Signal estimate: $N_A^{sig} = N_A^{data} - N_A^{bkg} - N_A^{Z+jets} = N^{sig}(N_X^{data}, N_X^{bkg}, R, c_X)$

Fake estimate: $N^{Z+jets} = (N_A^{data} - N_A^{bkg}) \times (1 - \dfrac{N_A^{sig}}{N_A^{data} - N_A^{bkg}})$

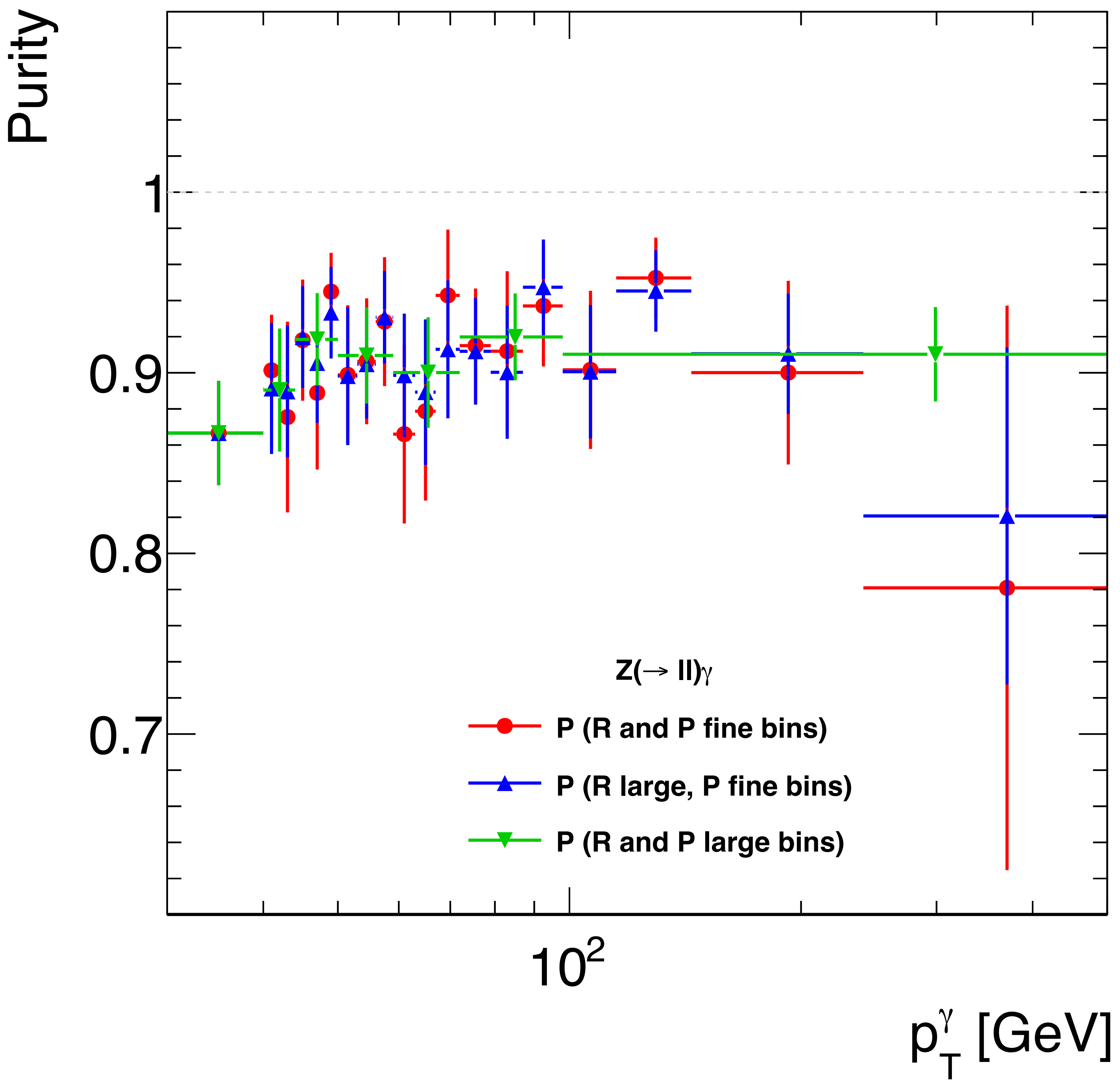
Purity

Z+jets estimation Strategy

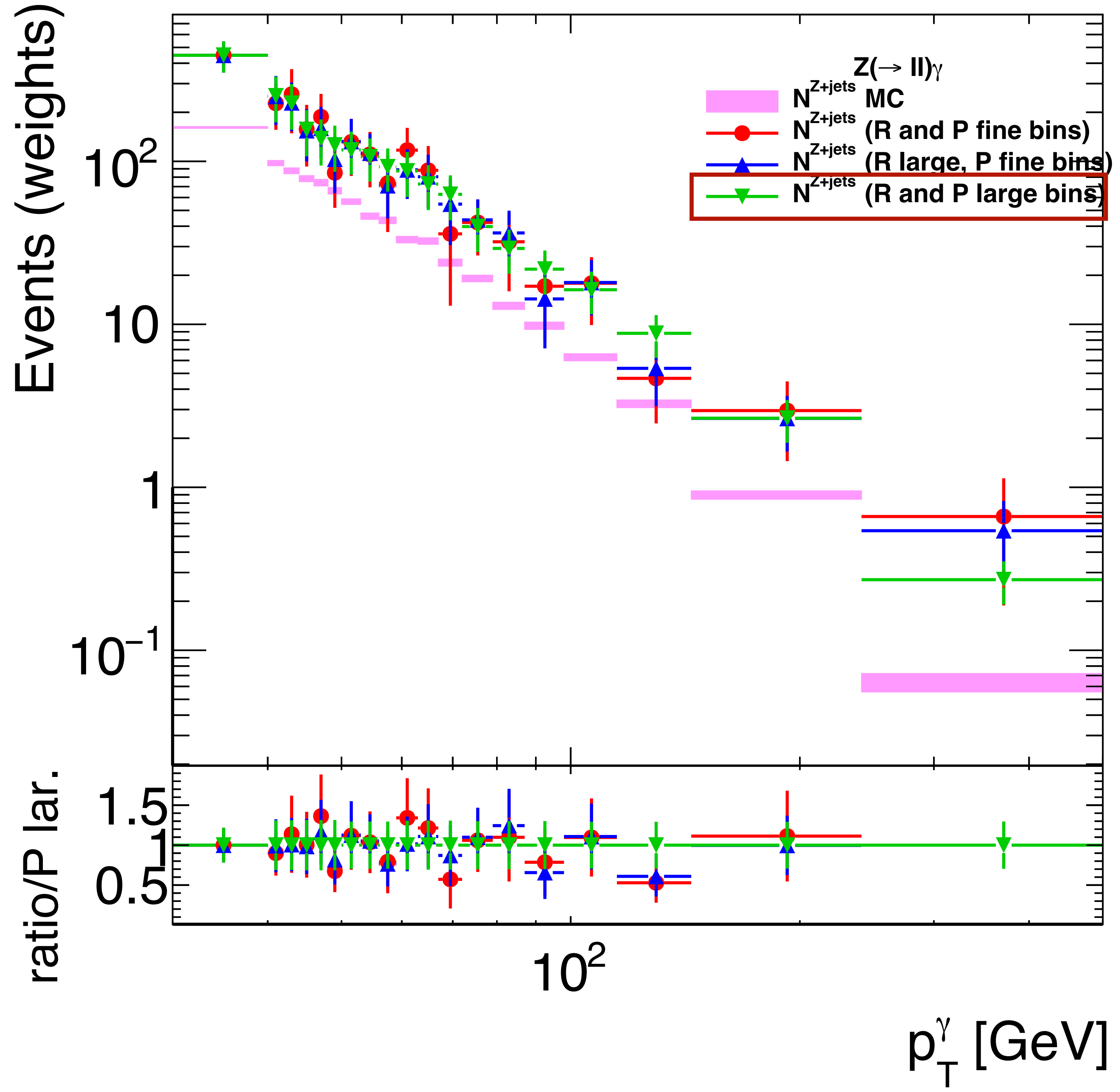
- Study **correlation factor R** as a function of variables
- Optimise binning by finding compromise between statistics and trend
  - R and purity computed in bins larger than the nominal binning of the distributions, so that can combine both the **high statistics** and **preservation of the distribution trend.**
  - If no clear trend, use only one bin for R computation



R computed with bin-by-bin or large bins methods



purity computed with bin-by-bin or large bins methods



Z+jets estimation

Uncertainties estimation for Z+jets

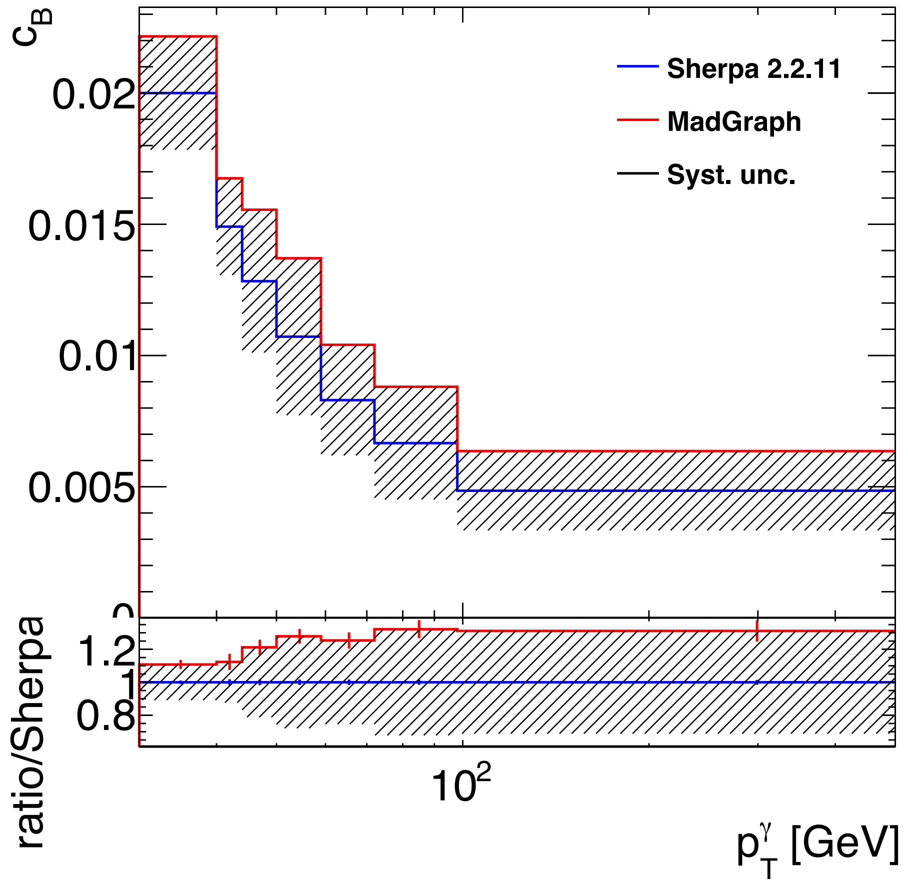
- **Statistical**
- **Signal leakage parameters**: Comparing with MadGraph
- **Correlation factor R**: Varying the definition of the CRs.

Anti-tight: use **LoosePrime3** and **LoosePrime5** to deduce the systematics uncertainty;

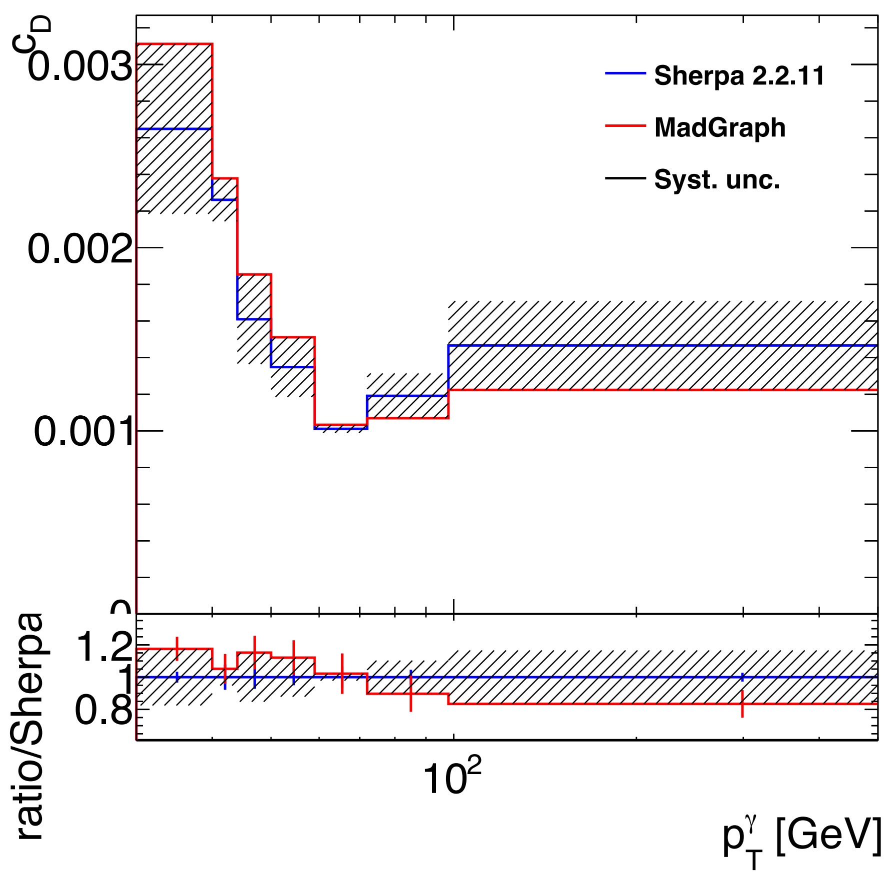
Isolation gap: E_T^{gap} is varied to **1GeV** and **3GeV**

- **Background**: the uncertainties of other background sources are propagated through the ABCD method.

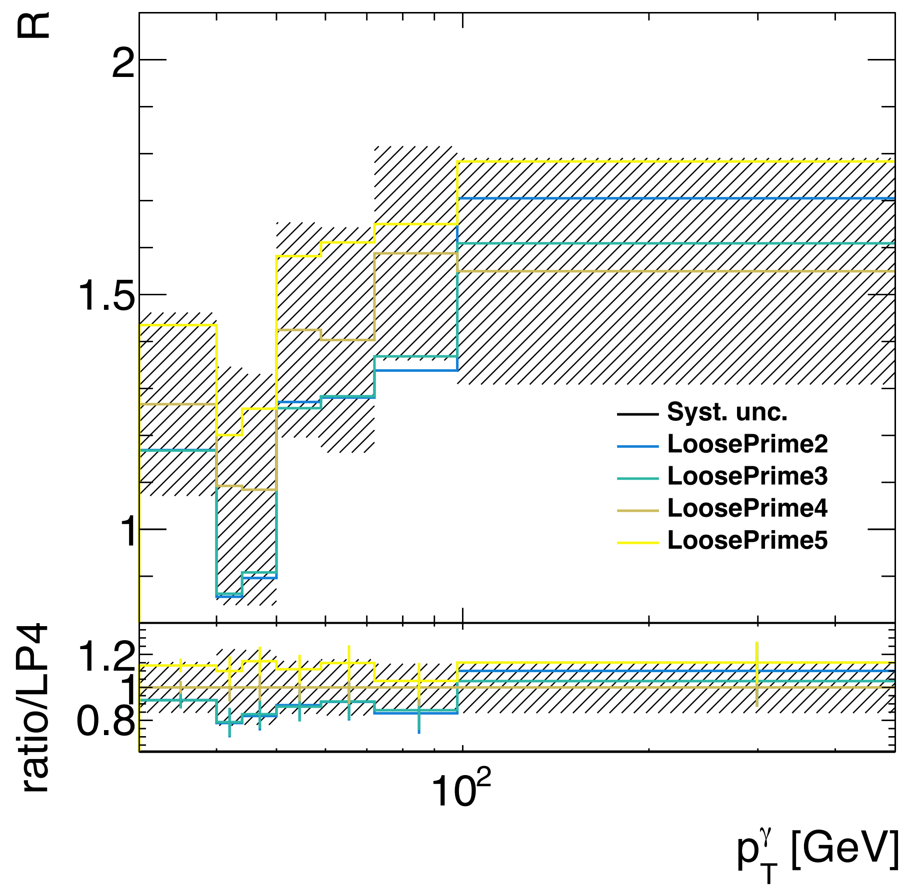
Signal leakage c_B



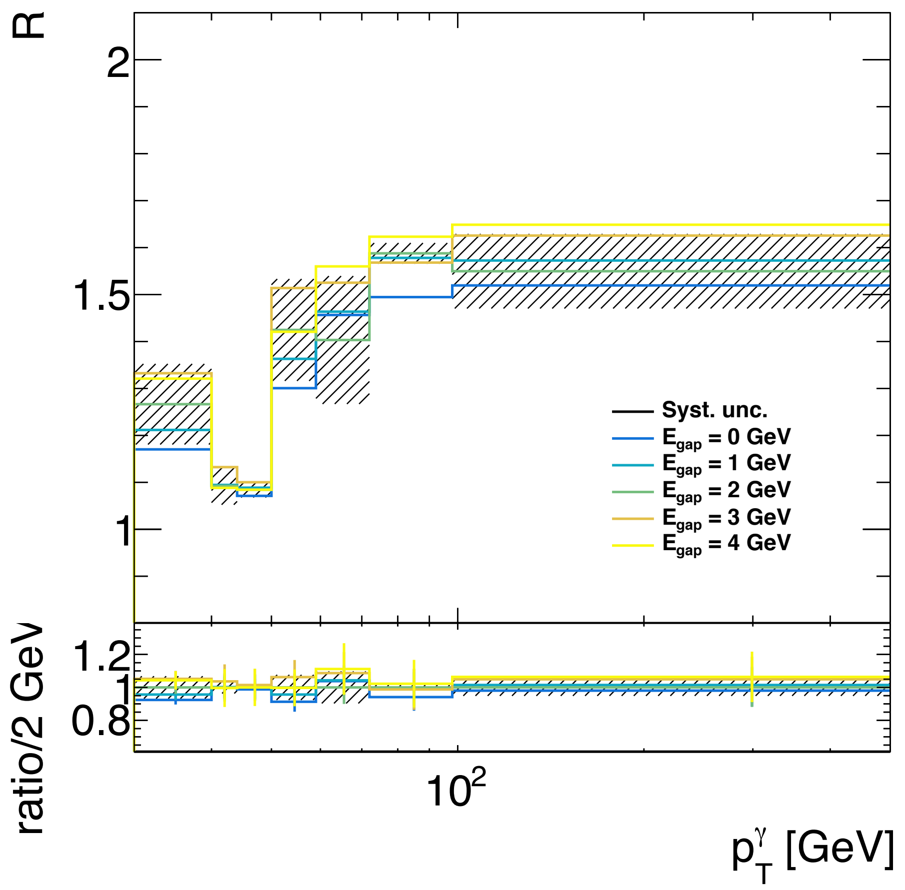
Signal leakage c_D



anti-tight ID



Isolation gap



Results

Source	ee ($N^{Z+\text{jets}}$ = 4 002.6)	$\mu\mu$ ($N^{Z+\text{jets}}$ = 5 884.8)	ee + $\mu\mu$ ($N^{Z+\text{jets}}$ = 97'
Statistical	274.6 (6.9%)	406.9 (6.9%)	465.0 (4.8%)
Background	233.3 (5.8%)	291.5 (5.0%)	381.6 (3.9%)
Generator	403.5 (10.1%)	511.1 (8.7%)	836.6 (8.6%)
E_{gap}	305.6 (7.6%)	501.1 (8.5%)	680.5 (7.0%)
Anti-tight	795.6 (19.9%)	1 214.6 (20.6%)	1 931.3 (19.8%)
Total uncertainties	906.0 (22.6%)	1 392.7 (23.7%)	2 184.4 (22.4%)

Anti-tight	LoosePrime4
Isolation gap	2 GeV
R	1.30 ± 0.04 (stat.) ± 0.23 (syst.)
c_B ($\times 10^{-3}$)	13.4 ± 0.1 (stat.) ± 2.1 (syst.)
c_C ($\times 10^{-3}$)	56.1 ± 0.2 (stat.) ± 0.2 (syst.)
c_D ($\times 10^{-3}$)	1.9 ± 0.0 (stat.) ± 0.2 (syst.)
$N_A^{data} - N_A^{bkg}$	91 704 ± 311 (stat.) ± 566 (syst.)
$N_B^{data} - N_B^{bkg}$	3 554 ± 60 (stat.) ± 9 (syst.)
$N_C^{data} - N_C^{bkg}$	15 853 ± 127 (stat.) ± 31 (syst.)
$N_D^{data} - N_D^{bkg}$	3 825 ± 62 (stat.) ± 2 (syst.)

Background estimation — Pileup

Data-driven Method

- Photon comes from a vertex different from leptons
- $\Delta Z = Z_{PV} - Z_{\gamma}$ is **wider in pileup events** than in single pp events
- Pileup estimation is done through the **pileup fraction**: $N_{PU} = f_{PU} \cdot N_{data}$

$$f_{PU} = \frac{1}{N_{\text{Data, pixel conv}}} \cdot \frac{N^{|\Delta z|>50\,\text{mm}}_{\text{Data, pixel conv}} - N^{|\Delta z|>50\,\text{mm}}_{Z\gamma\text{MC, pixel conv}}}{P(\Delta z > 50\ \text{mm})}$$

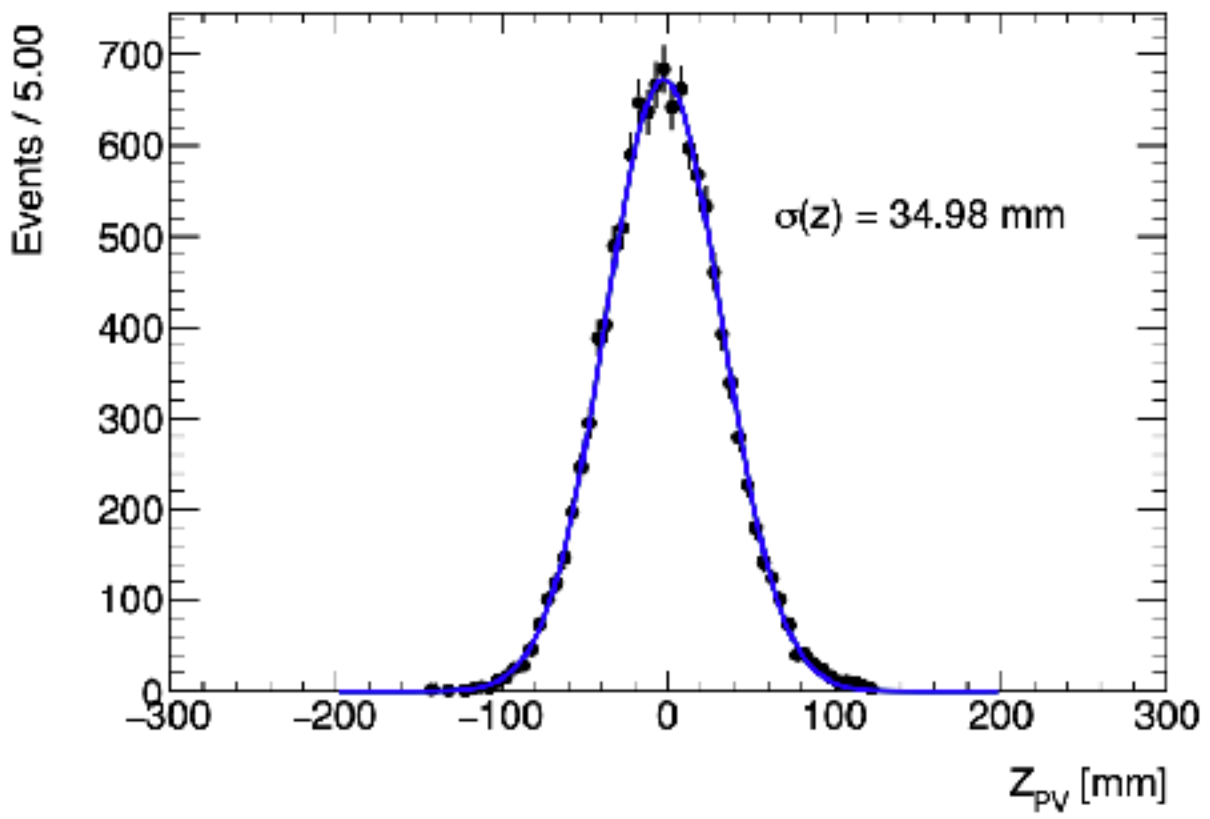
  - Only photons that converted in the Inner Detector are considered to get a better resolution $\sigma(z)$
  - f_{PU} is computed in bins of N_{jets} and p_T^{γ}

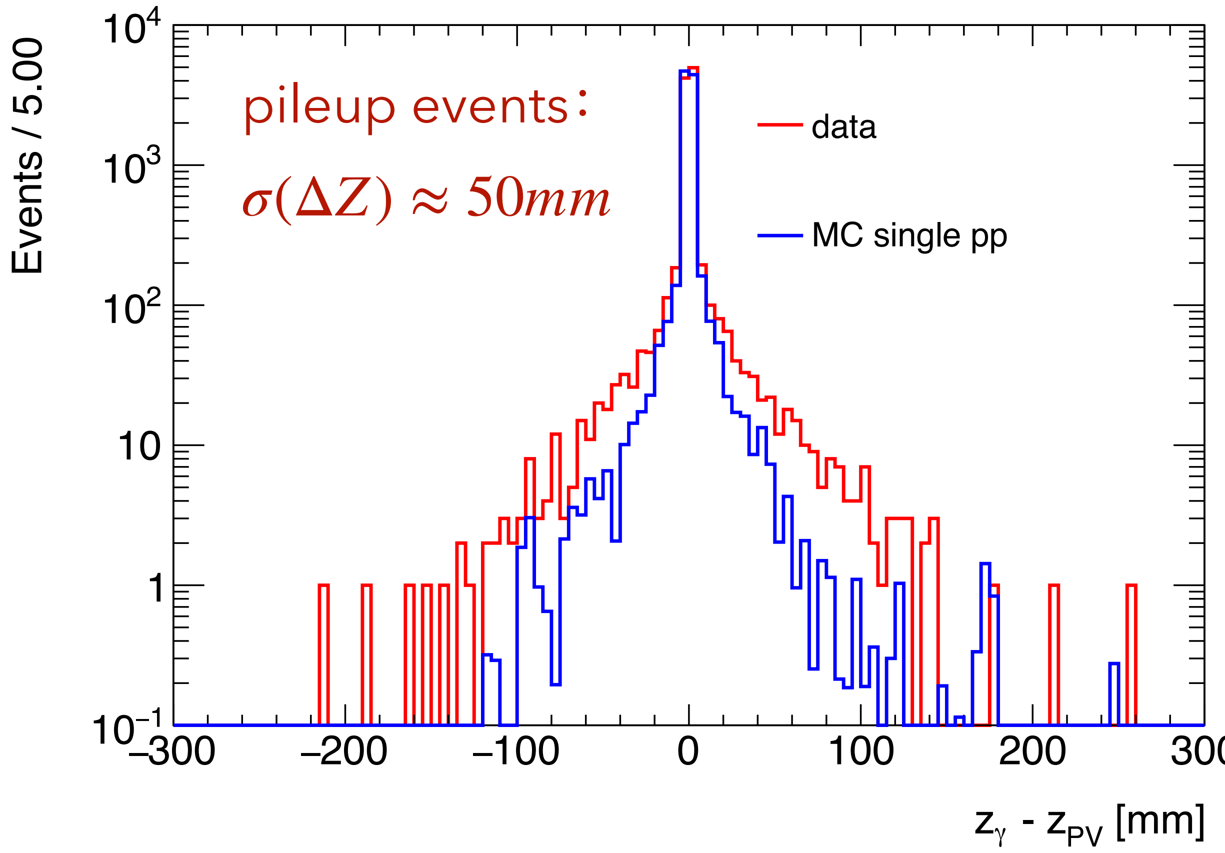
Shape information

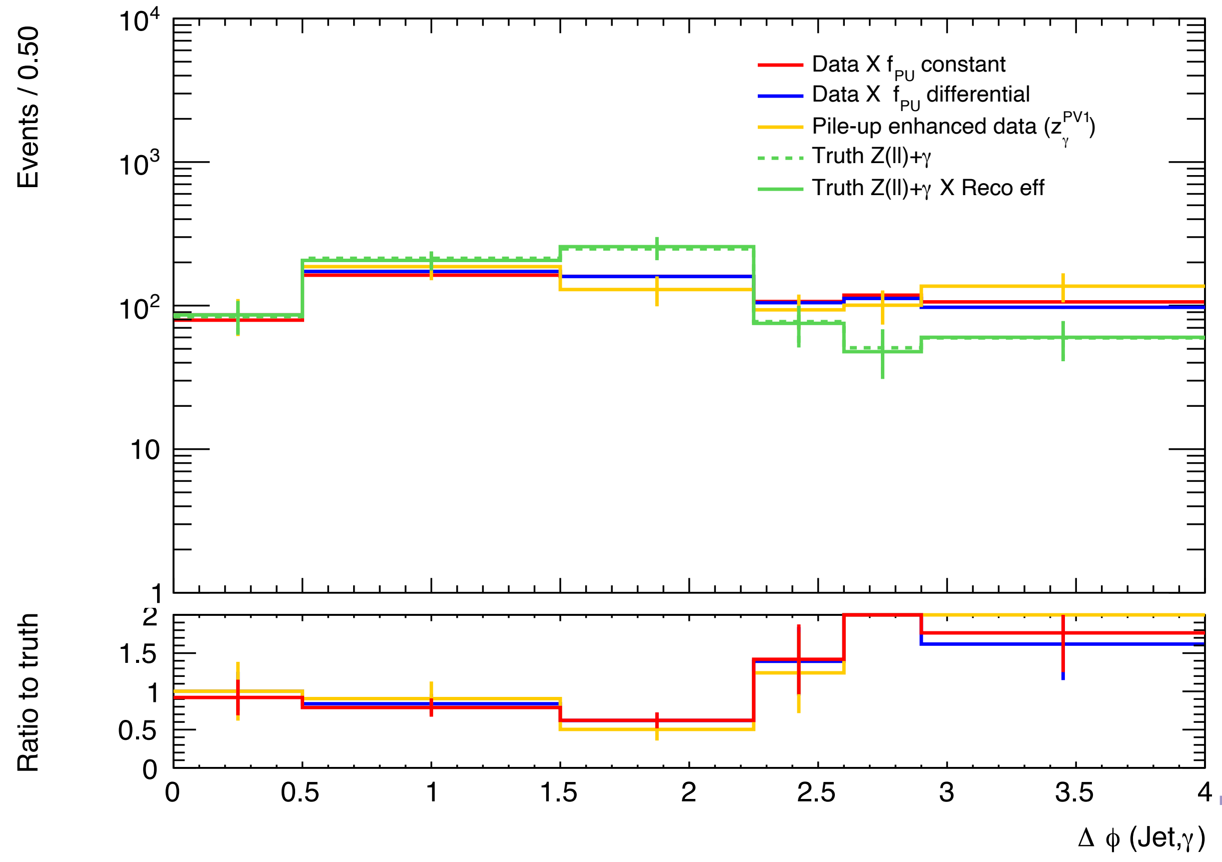
- **extracted** from **truth samples** by merging Z+jets and a single photon samples.

Uncertainty for pileup estimation

- difference between the **truth sample** and a Pile-up enriched sample
  - The pile-up enriched sample is built by selecting only photons pointing to the second hardest vertex



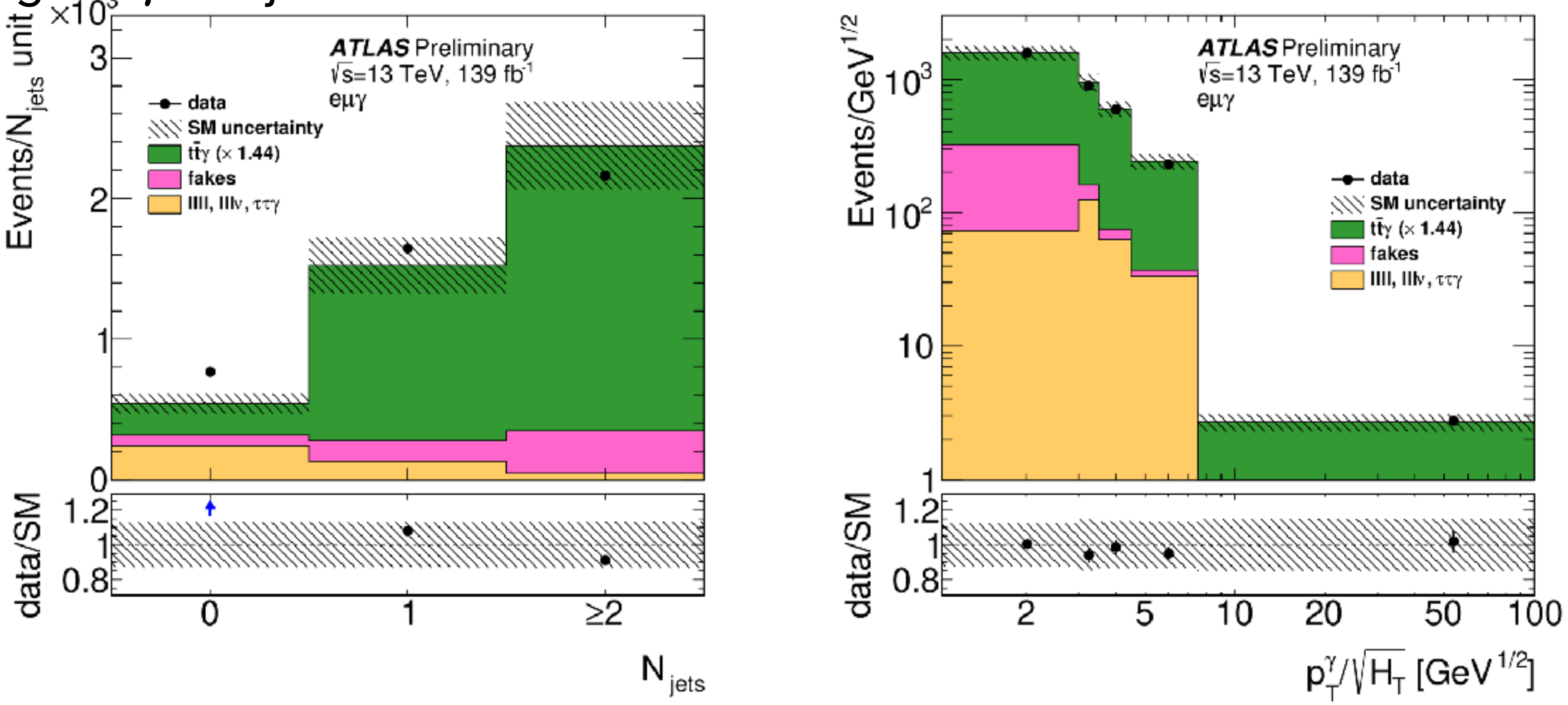




Data/MC comparison

Control region (Two opposite sign, same flavour leptons)

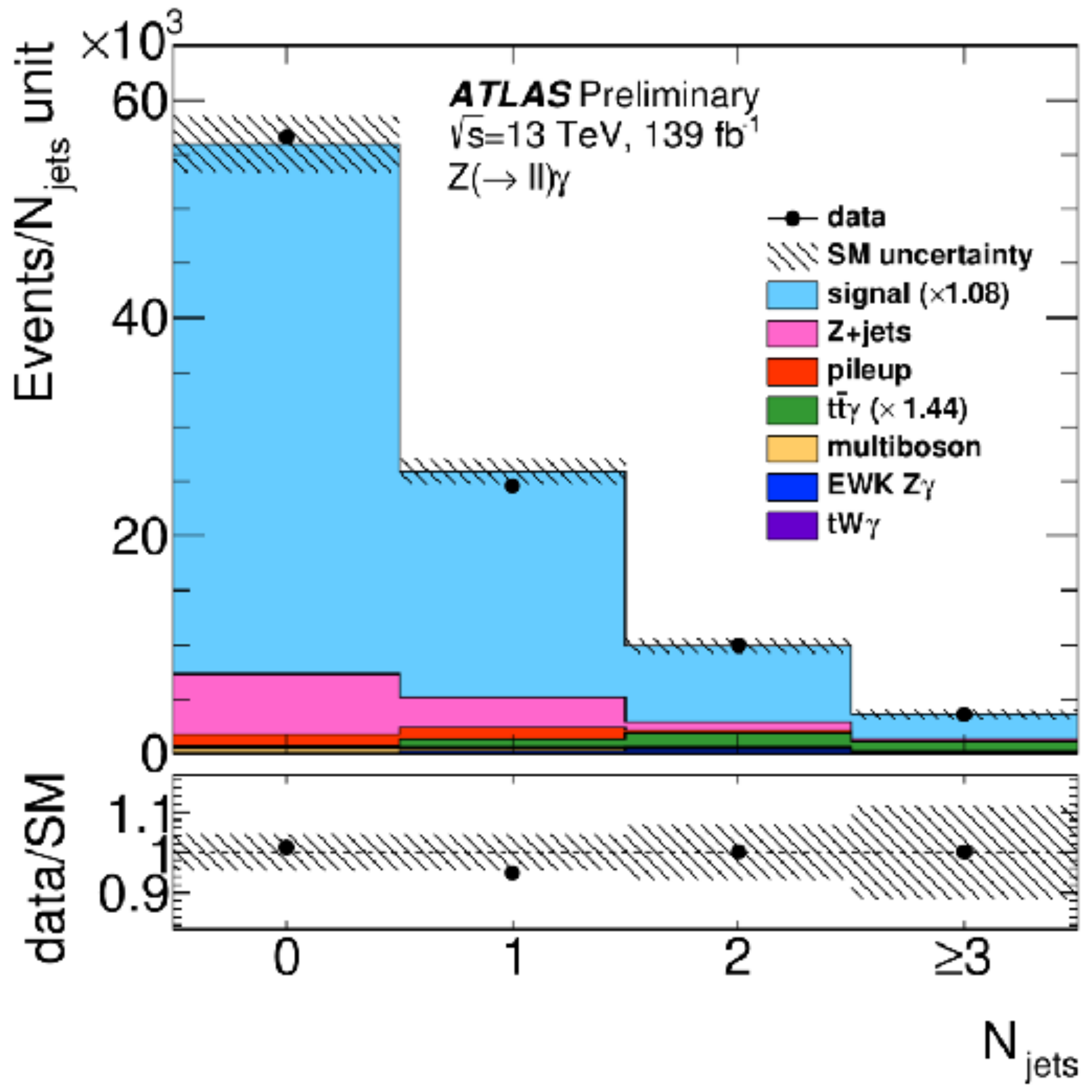
- Background dominated by Z + jets.
- Other minor background estimated directly by MC.
- Pileup events also estimated by Data-driven method.
- Take $e\mu\gamma$ **channel** as a control region (**no contribution from Z boson**)
  - Dominated by $t\bar{t}\gamma$ contribution, easy to **check the modelling of** $t\bar{t}\gamma$
  - Checking **the fake photon estimation**, including jets-related variables
  - Slight **mismodelling** of $t\bar{t}\gamma$ at **0 jets** is observed

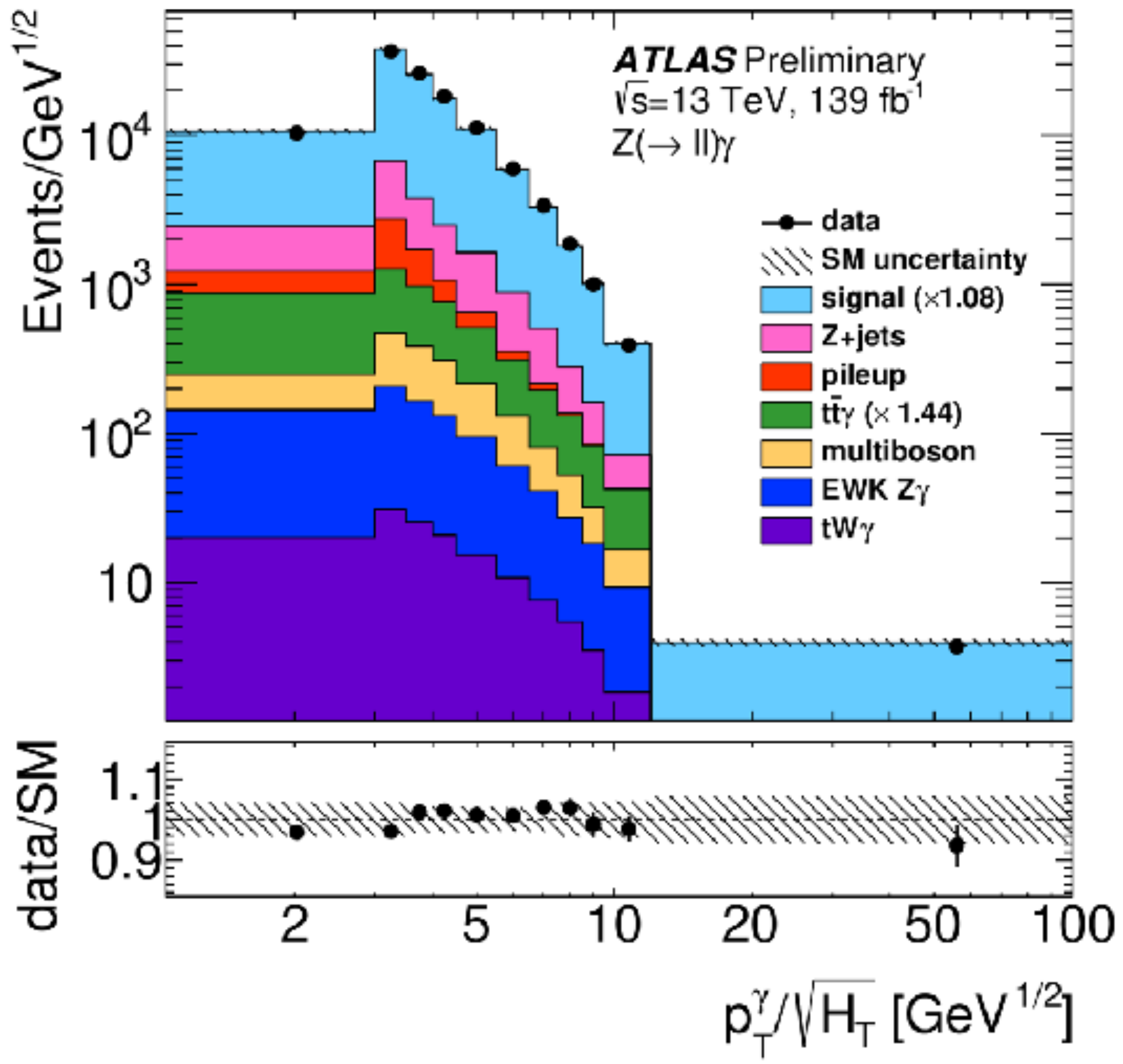


Data/MC comparison

- Signal region (Two opposite sign, different flavour leptons)
  - The baseline signal sample Sherpa 2.2.11 is scaled by a normalisation factor of **1.08** to match the ratio in data
  - A general good agreement is observed between Data and SM prediction
    - The systematic uncertainty includes experimental uncertainties and background uncertainties

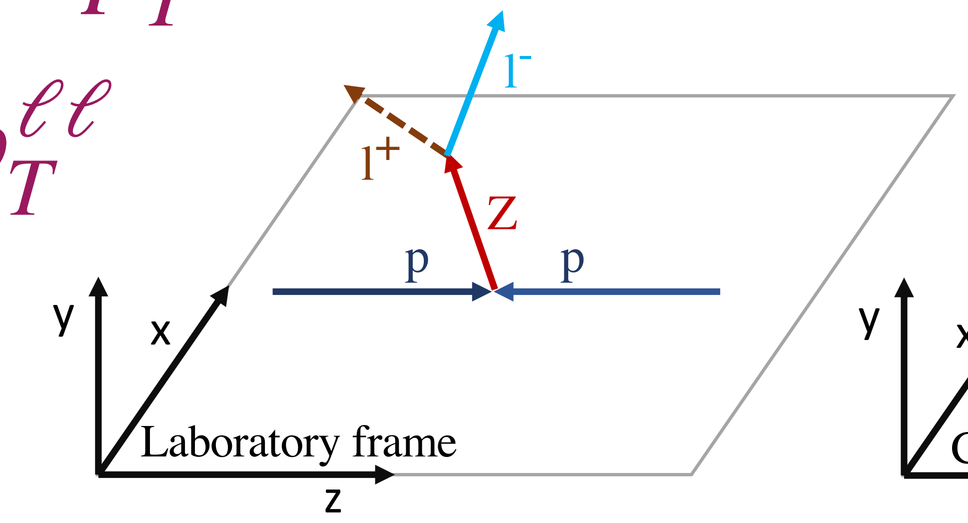
Source	$ee + \mu\mu$
$Z\gamma$+jets signal	73 500 ±50 (stat.) ± 2 600 (syst.)
Z + jets	9 800 ±460 (stat.) ± 2 100 (syst.)
$t\bar{t}\gamma$	3 600 ±10 (stat.) ± 540 (syst.)
pile-up	2 500 ±70 (stat.) ± 700 (syst.)
multiboson	950 ±5 (stat.) ± 160 (syst.)
$tW\gamma$	150 ±1 (stat.) ± 45 (syst.)
Total prediction	90 500 ±500 (stat.) ± 3 500 (syst.)
Data	96 410

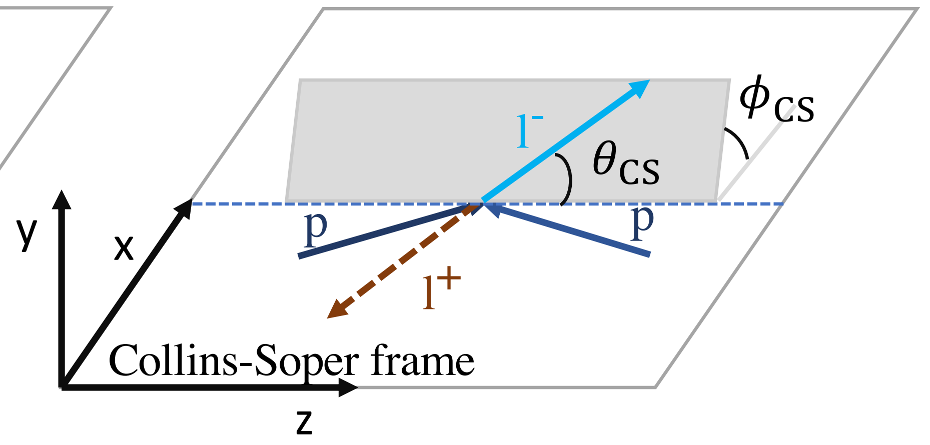




Observables

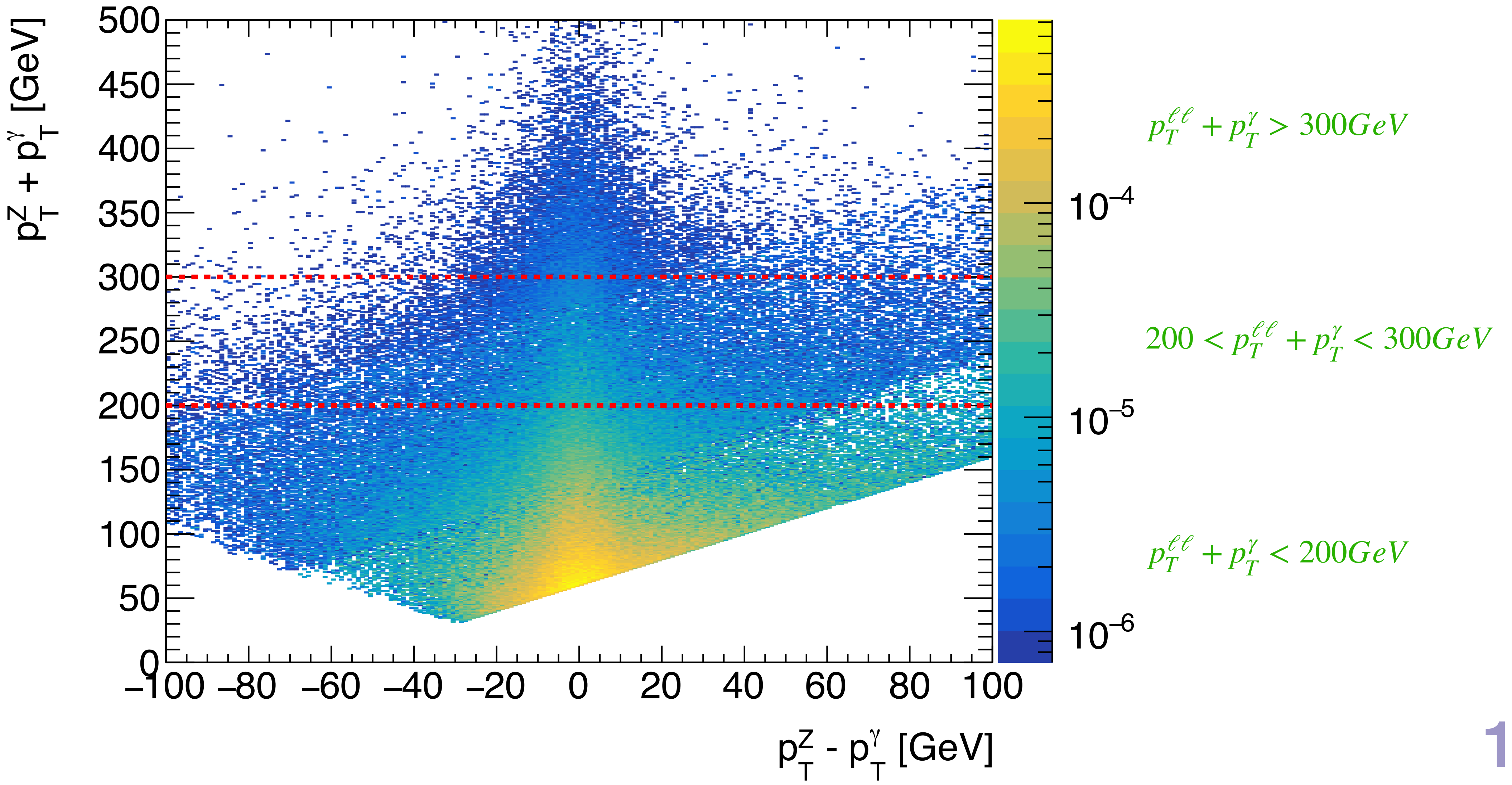
- 1D observables
  - Interesting for QCD studies: N^{jets}, p_T^{Jet1}, p_T^{Jet2}, p_T^{Jet2}/p_T^{Jet1}, $m_{\ell\ell\gamma j}$, m_{jj}
  - used in other analysis: H_T, $p_T^{\gamma}/\sqrt{H_T}$, $\Delta\Phi(Jet,\gamma)$, $\Delta R(\ell,\ell)$, p_T^{ll}
- QCD-sensitive 2D observables
  - $p_T^{\ell\ell\gamma}/m_{\ell\ell\gamma}$ in 3 slices of $m_{\ell\ell\gamma}$
  - $p_T^{\ell\ell} - p_T^{\gamma}$ in 3 slices of $p_T^{\ell\ell} + p_T^{\gamma}$
  - $p_T^{\ell\ell\gamma j}$ in 3 slices of $p_T^{\ell\ell\gamma}$
  - $p_T^{\ell\ell\gamma}/m_{\ell\ell\gamma}$, $p_T^{\ell\ell} - p_T^{\gamma}$, $p_T^{\ell\ell} + p_T^{\gamma}$, $p_T^{\ell\ell\gamma j}$ inclusively
- Polarisation-sensitive 2D observables
  - $cos\theta_{CS}$ in 5 bins of $p_T^{\ell\ell}$
  - ϕ_{CS} in 5 bins of $p_T^{\ell\ell}$





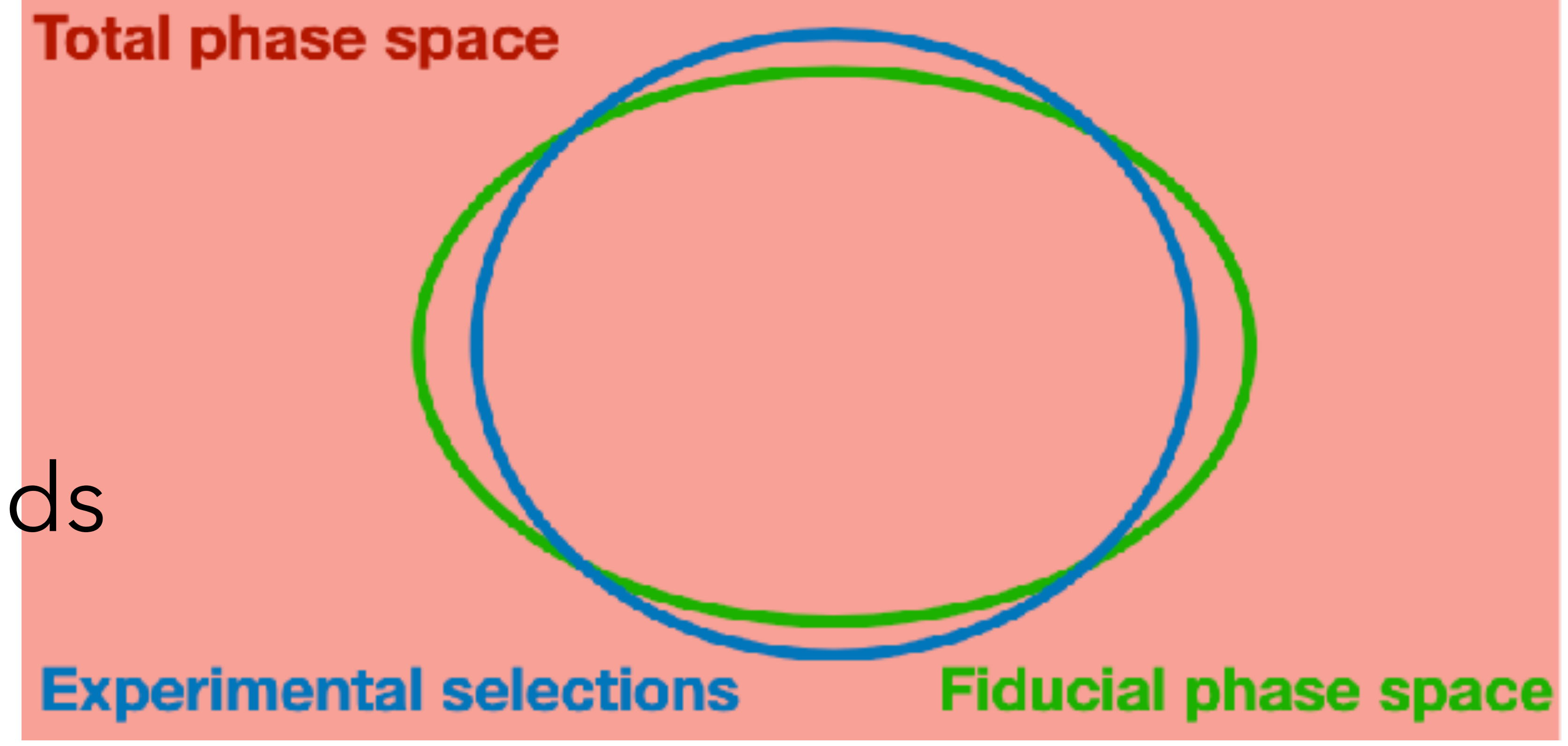
Variables are separated in two types:

- **hard variables**: represent the hard scale of the process (non- zero at LO)
- **resolution variables**: sensitive to additional QCD variations

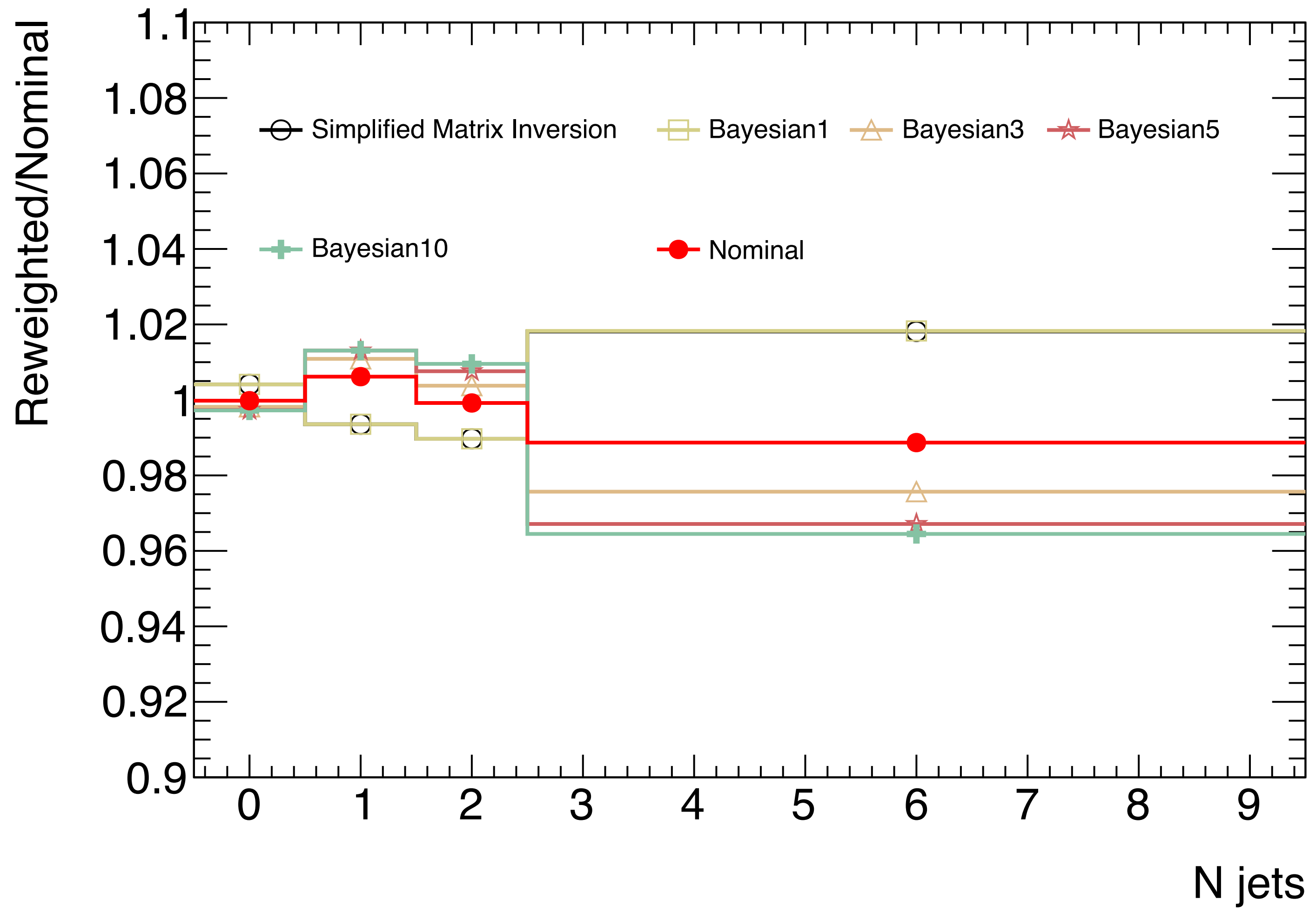


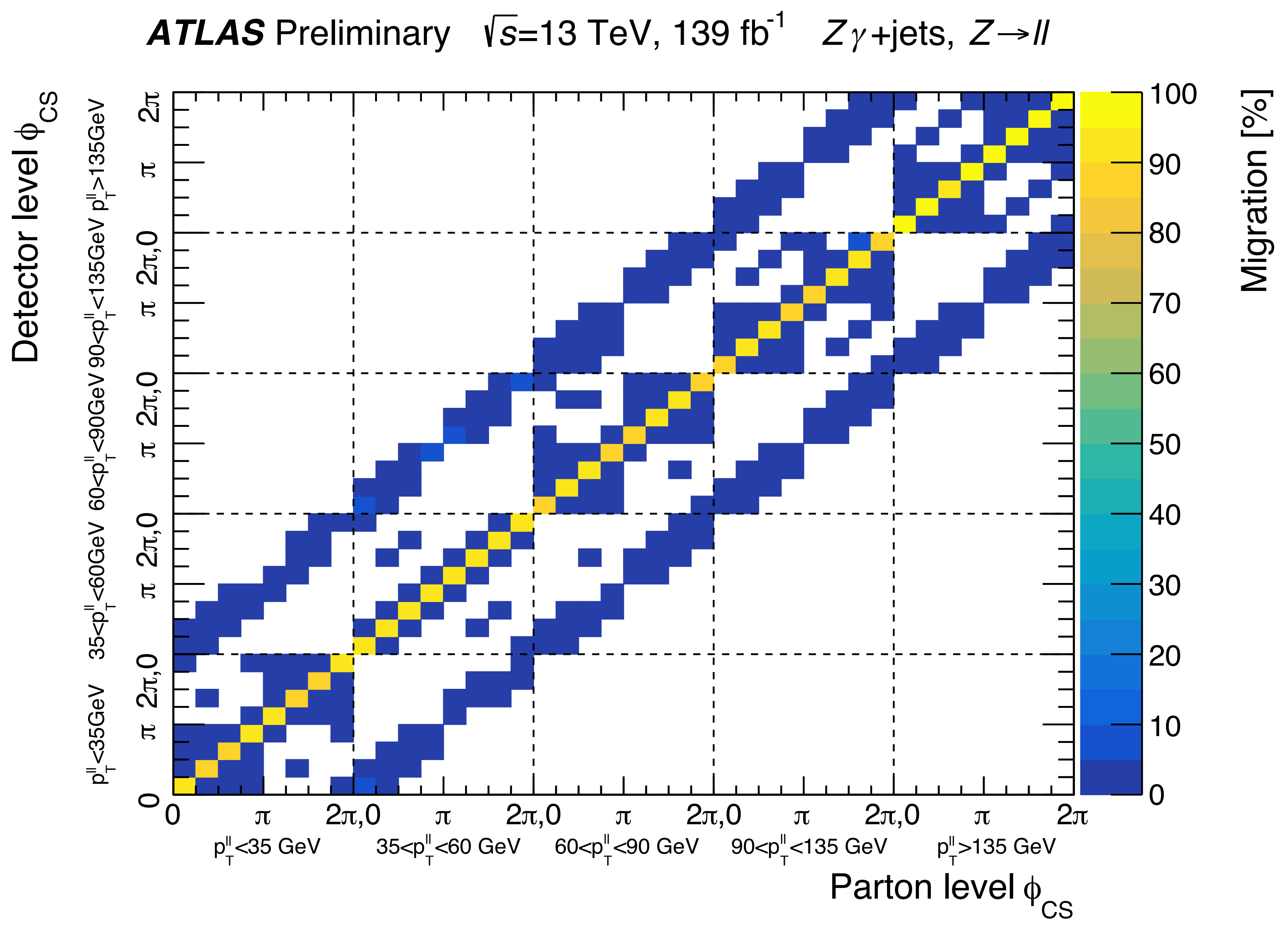
Unfolding

- Two iterations Bayesian Unfolding Method
  - Smaller bias and statistical uncertainty comparing with other methods
  - Unfolding statistical uncertainty propagated by MC toys



- 2D unfolding method applied for polarisation 2D variables
  - angular ($cos\theta_{CS}, \phi_{CS}$) observables studied as a function of $p_T^{\ell\ell}$
  - nontrivial dependencies due to reconstruction and detector effects
  - transforming 2D histograms into 1D histograms



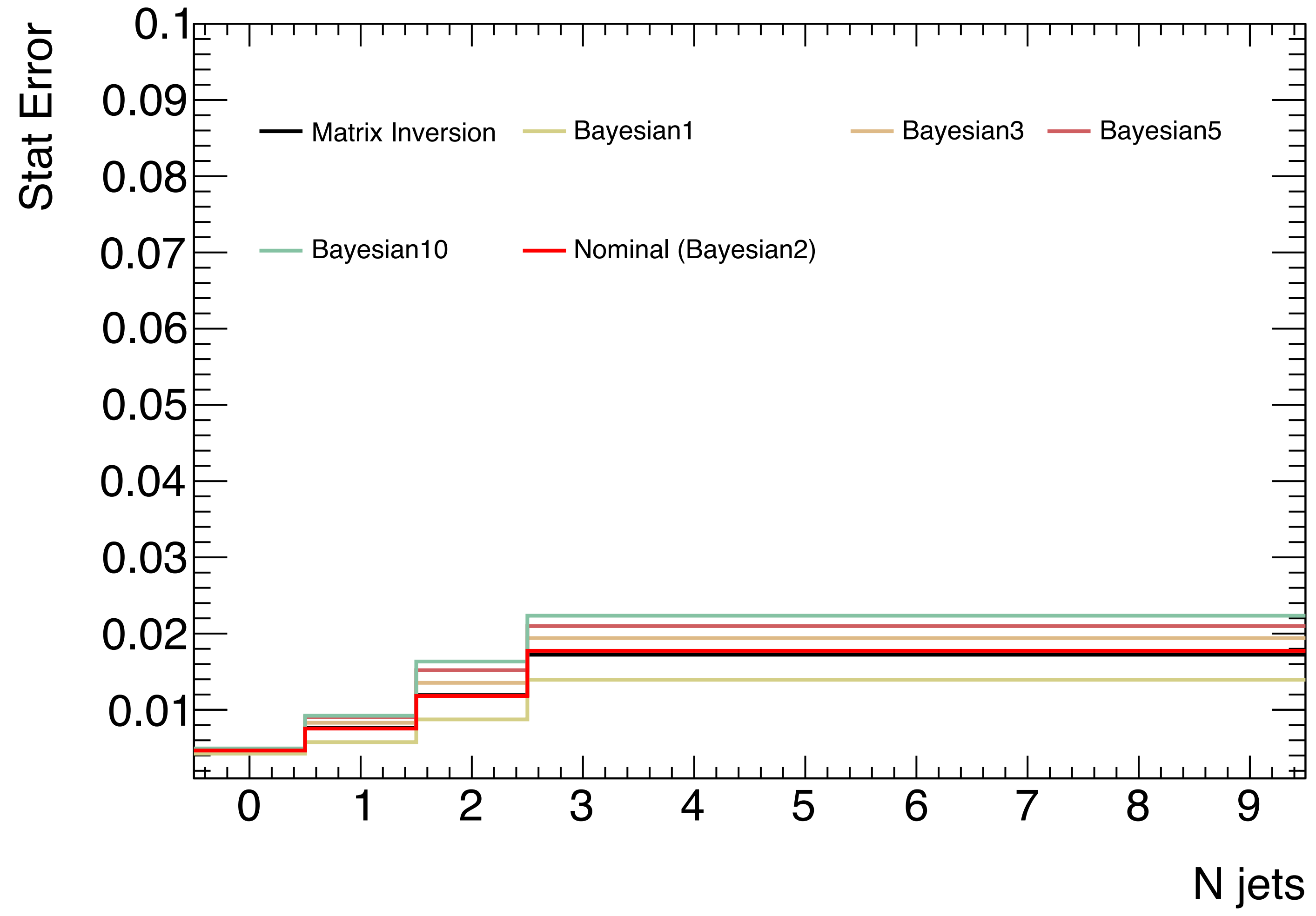


$p_T^Z \in (0, 35)$ — 1st differential bin — 8 $\cos\theta_{CS}$ bins

$p_T^Z \in (35, 60)$ — 2nd differential bin — 8 $\cos\theta_{CS}$ bins

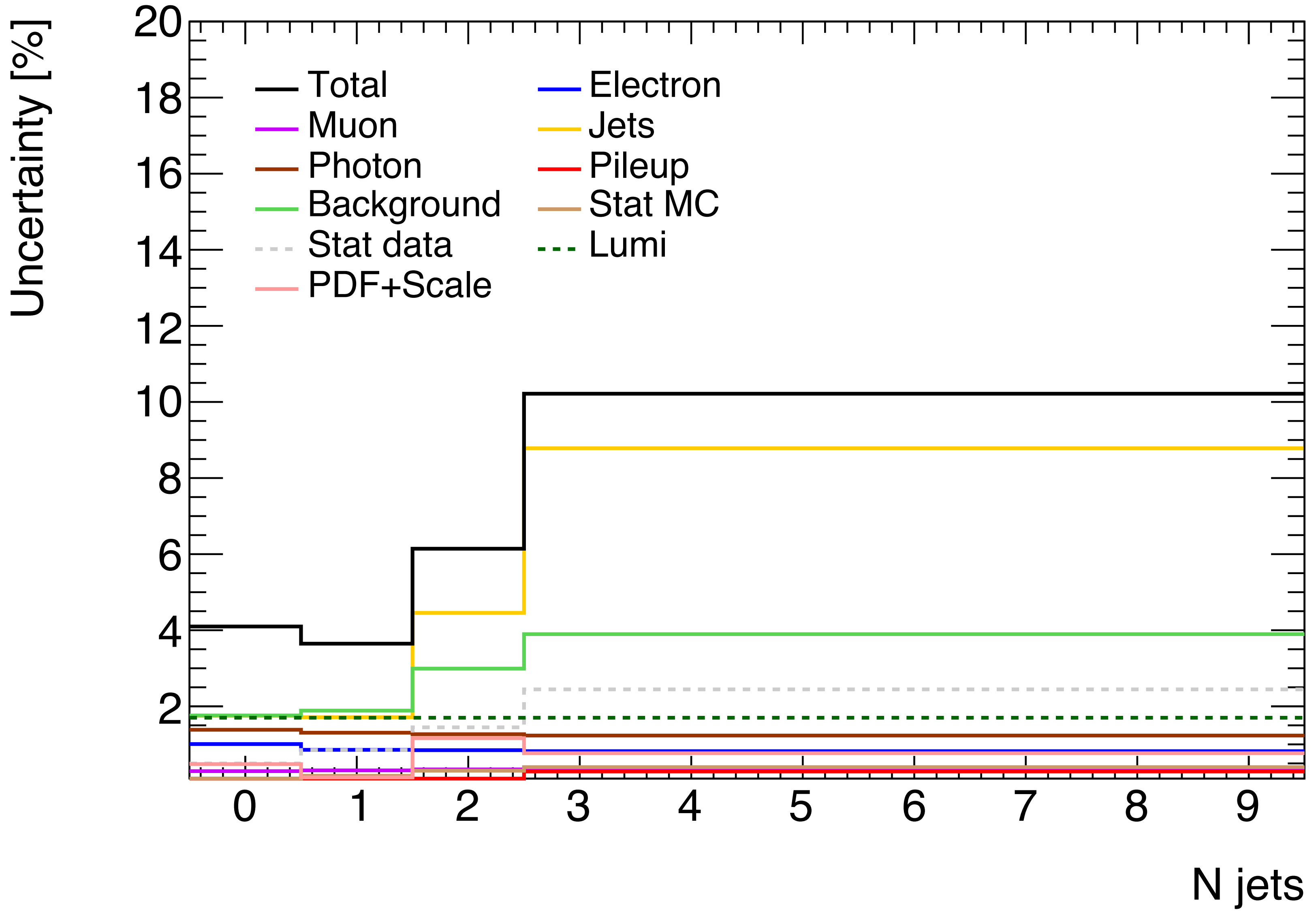
...

$p_T^Z > 135 GeV$ — 5th differential bin — 8 $\cos\theta_{CS}$ bins



Systematic uncertainties

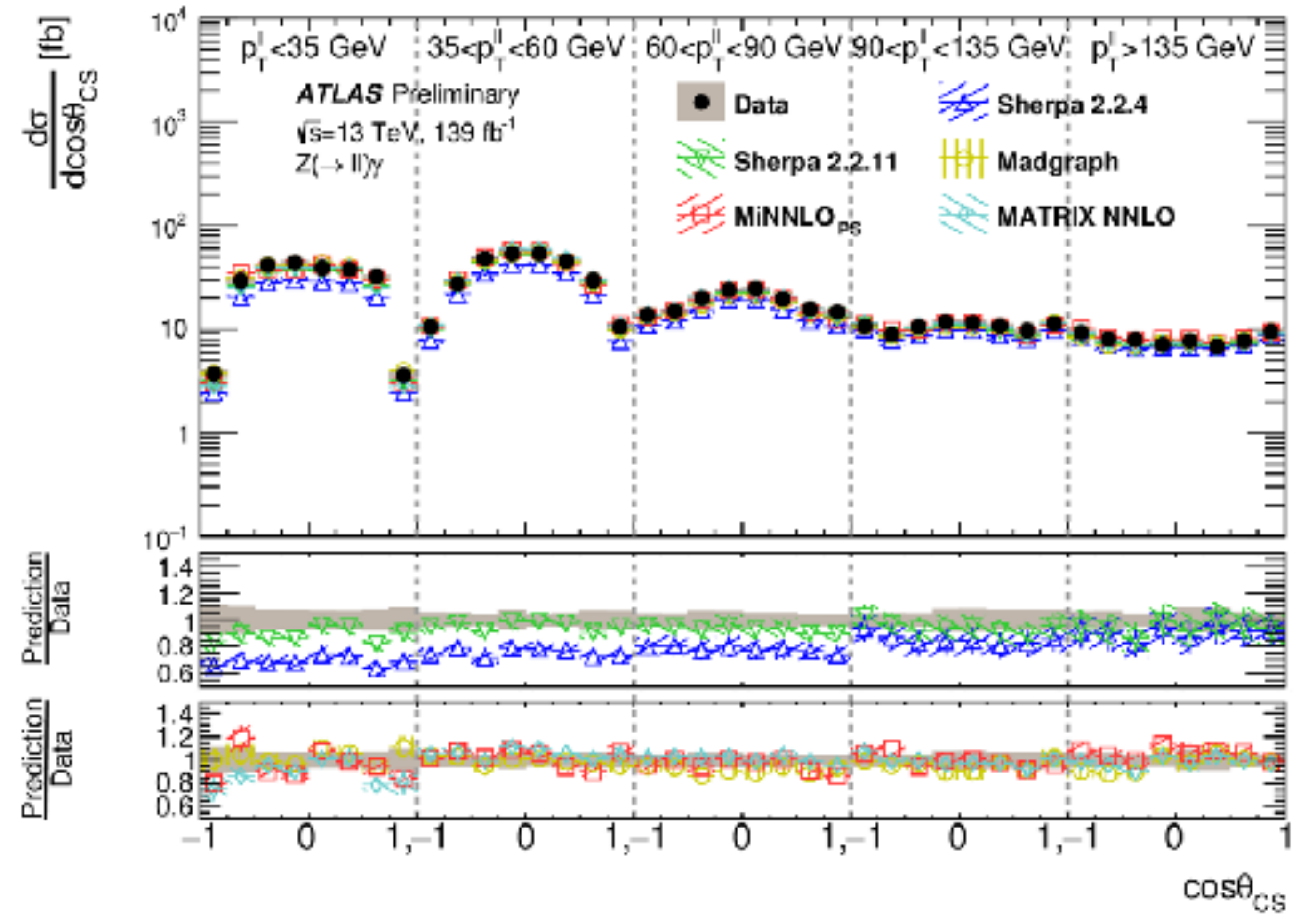
- Experimental systematics
  - Egamma/Jet/muons experimental systematics
- The statistical uncertainty in the unfolded distribution
  - Propagated with toys 1000 pseudo-Poisson experiments
- Unfolding bias
  - Data-driven closure test
- Theory uncertainties
  - Scale: 7 point variation of renormalization (μ_R) and factorization (μ_f) scale
  - PDF: NNPDF30_nnlo_as_0118 PDF set as nominal
  - α_S : NNPDF30_nnlo_as_0117 and NNPDF30_nnlo_as_0119
- Background cross section
  - A flat 30% is applied for each source, except for $t\bar{t}\gamma$ where 15% is applied
- Luminosity: 1.7%

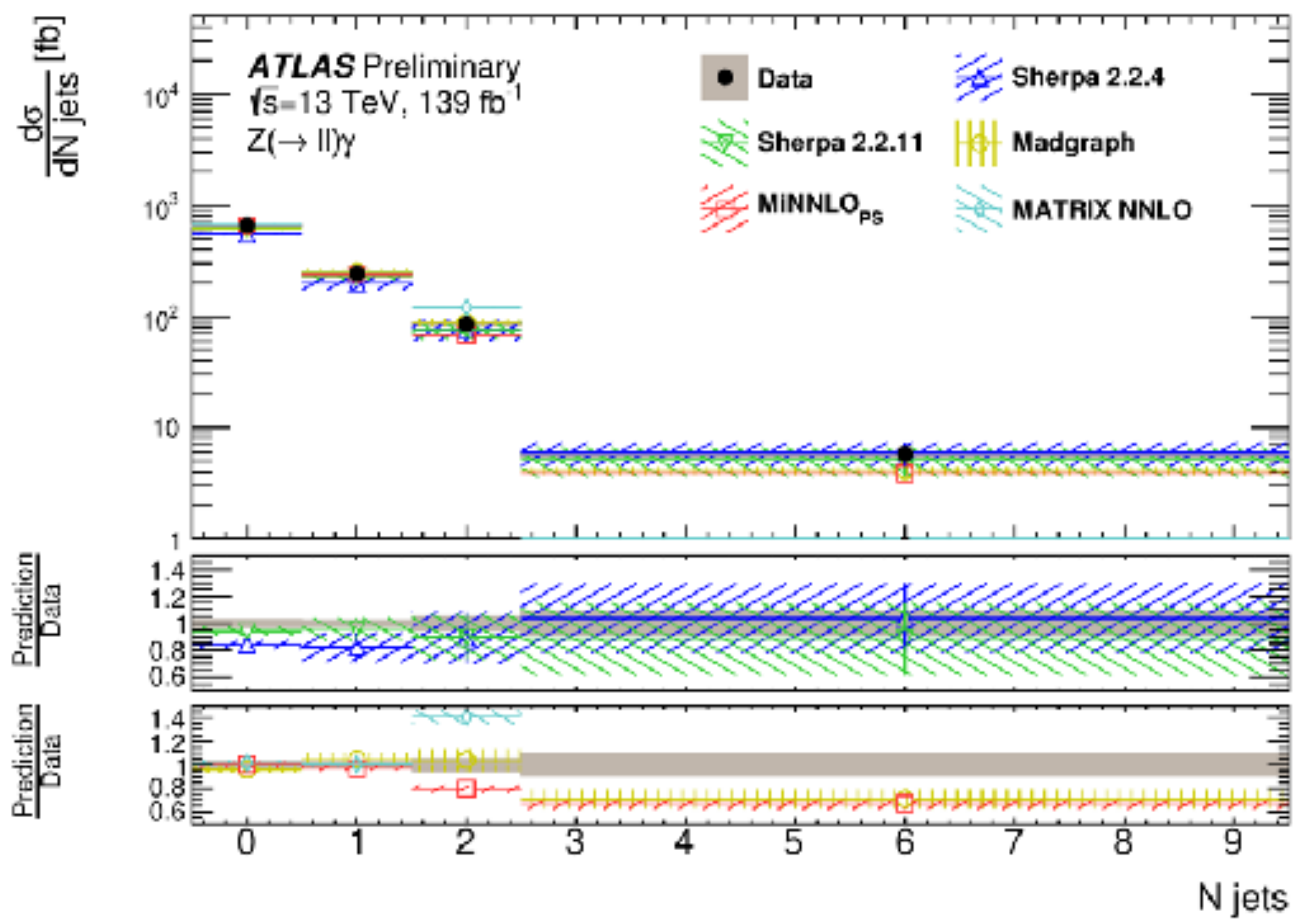


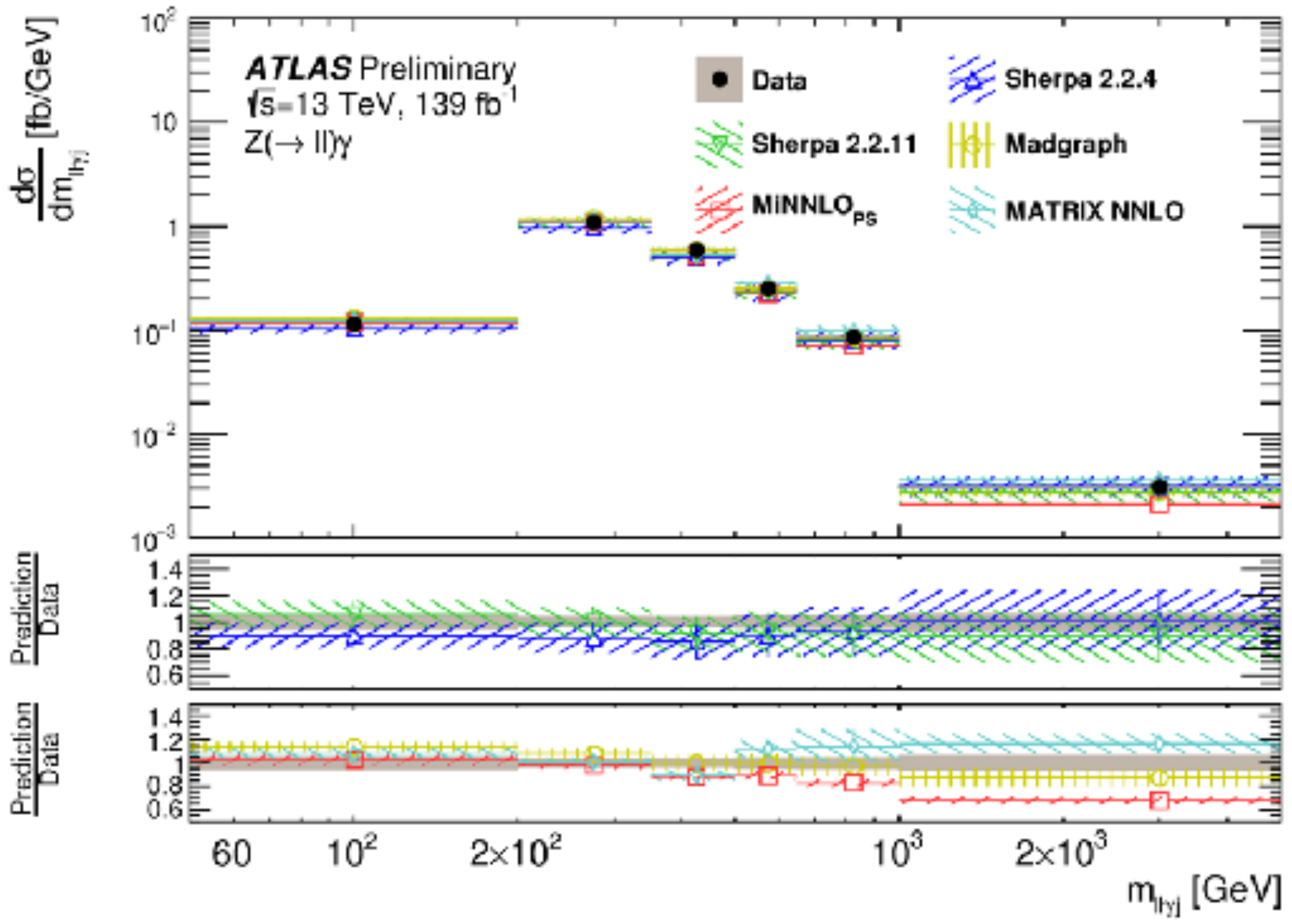
N_{Jet}	0	1	2	>2
Source	Uncertainty [%]			
Electrons	1.0	0.9	0.8	0.8
Muons	0.3	0.3	0.3	0.4
Jets	1.7	1.7	4.5	8.8
Photons	1.4	1.3	1.3	1.2
Pile-up	2.1	0.8	0.2	0.3
Background	1.8	1.8	3.0	4.4
Stat. MC	0.1	0.2	0.3	0.4
Stat. data	0.8	1.5	1.8	1.9
Luminosity	1.7	1.7	1.7	1.7
Theory	0.6	0.2	1.4	1.0
Total	4.2	3.8	6.3	10.3

Results

- Unfolded results compared with different theoretical predictions
  - Theoretical prediction include:
    - Sherpa 2.2.4 (LO), Sherpa 2.2.11 (NLO) and MadGraph5_aMC@NLO
    - NNLO predictions of $\mathrm{MiNNLO_{PS}}$ and MATRIX
  - Sherpa Samples underestimate the total cross section. Sherpa 2.2.11 (NLO) better describe the shape and cross section than Sherpa 2.2.4
  - NNLO **$\mathrm{MiNNLO_{PS}}$** and **MATRIX** generally well predict the observables, but with some discrepancy at high jet multiplicity







Conclusion

Summary

- Differential cross-section of $Z\gamma$ + jets production measured using full **Run-2 data**.
- Measured **1D and 2D observables** sensitive to **QCD and polarisation.**
- The results are compared to **MC generators** (Sherpa, MadGraph), as well as **MiNNLO$_{PS}$**, and NNLO fixed order calculation **MATRIX**
- Measurements are in general good agreement with the predictions.

Status

- Published CONF Conversion ATLAS-CONF-2022-047 on ICHEP2022
- In 2nd circulation
- The HEPData of polarisation variables will be used in polarisation interpretation
- EFT Study on $Z\gamma$ process is on going

Backup

Object definition

	Photons	Electrons	Muons	Jets
Algorithm	-	-	-	Anti-k_t (R = 0.4, Pflow)
Transverse momentum	$p_T > 30$GeV	$p_T > 30, 25$GeV	$p_T > 30, 25$GeV	$p_T > 30$ GeV if $\|\eta\| < 2.5$ $p_T > 50$ GeV if $\|\eta\| > 2.5$
Pseudorapidity	$\|\eta\| < 2.37$ excl. $1.37 < \|\eta\| < 1.52$	$\|\eta\| < 2.47$ excl. $1.37 < \|\eta\| < 1.52$	$\|\eta\| < 2.5$	$\|\eta\| < 4.4$
Impact parameter	-	$\|d_0/\sigma(d_0)\| < 5$ $\|z_0 \sin\theta\| < 0.5$ mm	$\|d_0/\sigma(d_0)\| < 3$ $\|z_0 \sin\theta\| < 0.5$ mm	-
Identification	Tight	Medium	Medium	-
Isolation	FixedCutLoose	FCLoose	PflowLoose_FixedRadIso	-
Pileup mitigation	-	-	-	JVT Medium if p_T <60 GeV & $\|\eta\| < 2.4$
Overlap removal	$\Delta R(\gamma, e) > 0.4$ $\Delta R(\gamma, \mu) > 0.4$	$\Delta R(e, j) > 0.4$ $\Delta R(e, \mu) > 0.2$	$\Delta R(u, j) > 0.4$	$\Delta R(j, \gamma) > 0.4$ $\Delta R(j, e) > 0.4$

Samples

- The nominal signal sample is **Sherpa 2.2.11** (0,1j @NLO+2,3,4j @LO)
- Two sources of background are estimated by data-driven methods:
  - **Z+jets** : Jet is misidentified as a photon
  - **Pileup photons** : Photon and Z-boson come from different vertex

	Process	Generator	PDF Set
Signal Samples	$Z\gamma$ 0,1j @NLO+2,3,4j @LO	Sherpa 2.2.11	NNPDF3.0nnlo
	$Z\gamma$ 0,1,2,3 j@ LO	Sherpa 2.2.4	NNPDF3.0nnlo
	$Z\gamma$ 0,1j @NLO	MadGraph	NNPDF30_nlo_as_0118
Background Samples	Z + jets 0j @NLO	PowhegBox	CT10
	$t\bar{t}\gamma$/ $tW\gamma$ LO	MadGraph5_aMC@NLO	NNPDF2.3lo
	$ZZ \rightarrow$ llll/ $W^{\pm}Z \rightarrow$ lllν 0,1j @NLO + 2,3j @LO	Sherpa 2.2.2	NNPDF3.0nnlo
	$WZ\gamma$/WWγ 0,1j @NLO + 2,3j @LO	Sherpa 2.2.11	N30NNLO
	EW $Z\gamma$	MadGraph	NNPDF3.0lo

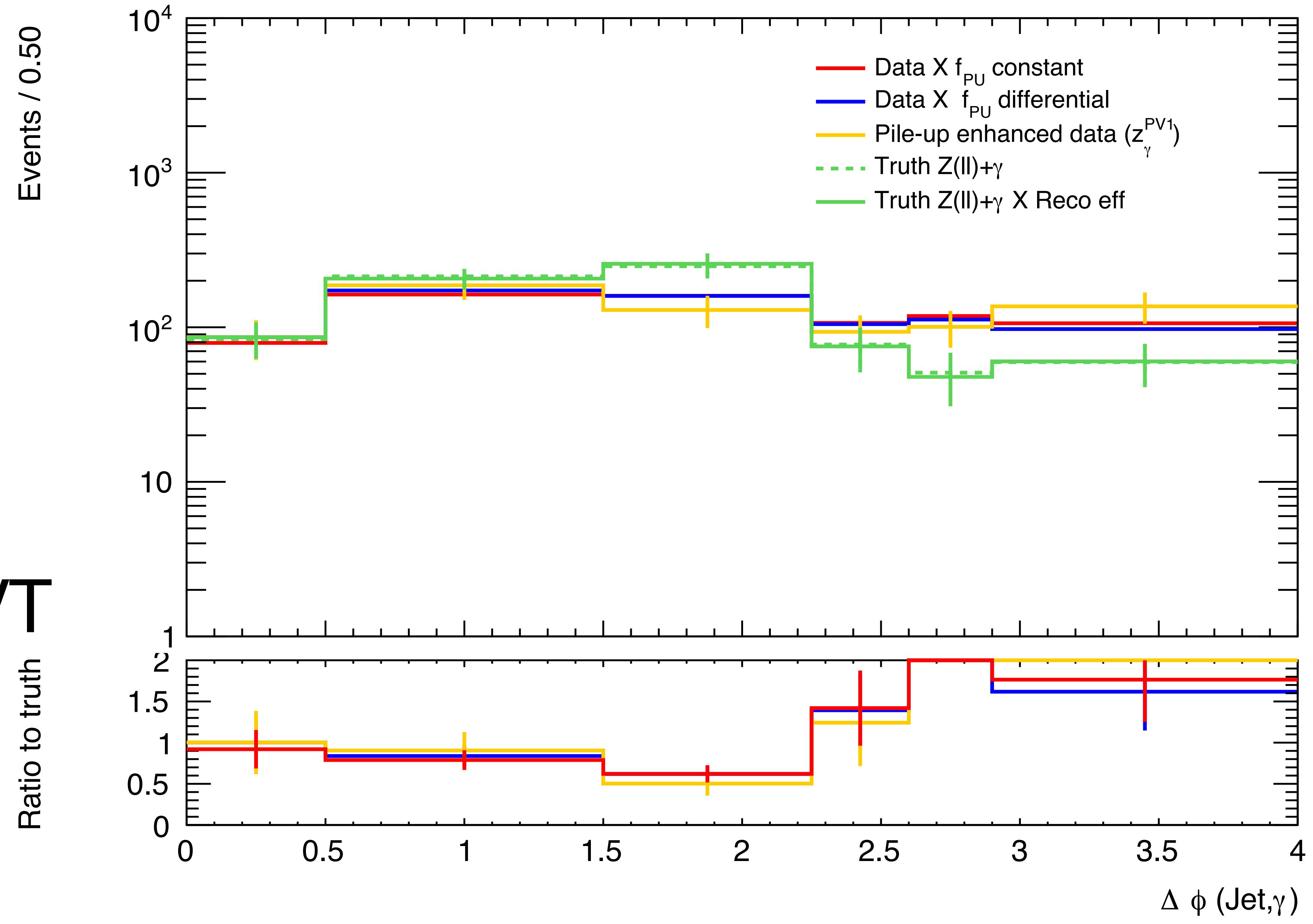
- Additional theory predictions compared to the results
  - MiNNLO$_{PS}$
  - Fixed order QCD calculations using the software MATRIX with CT14NNLO PDF

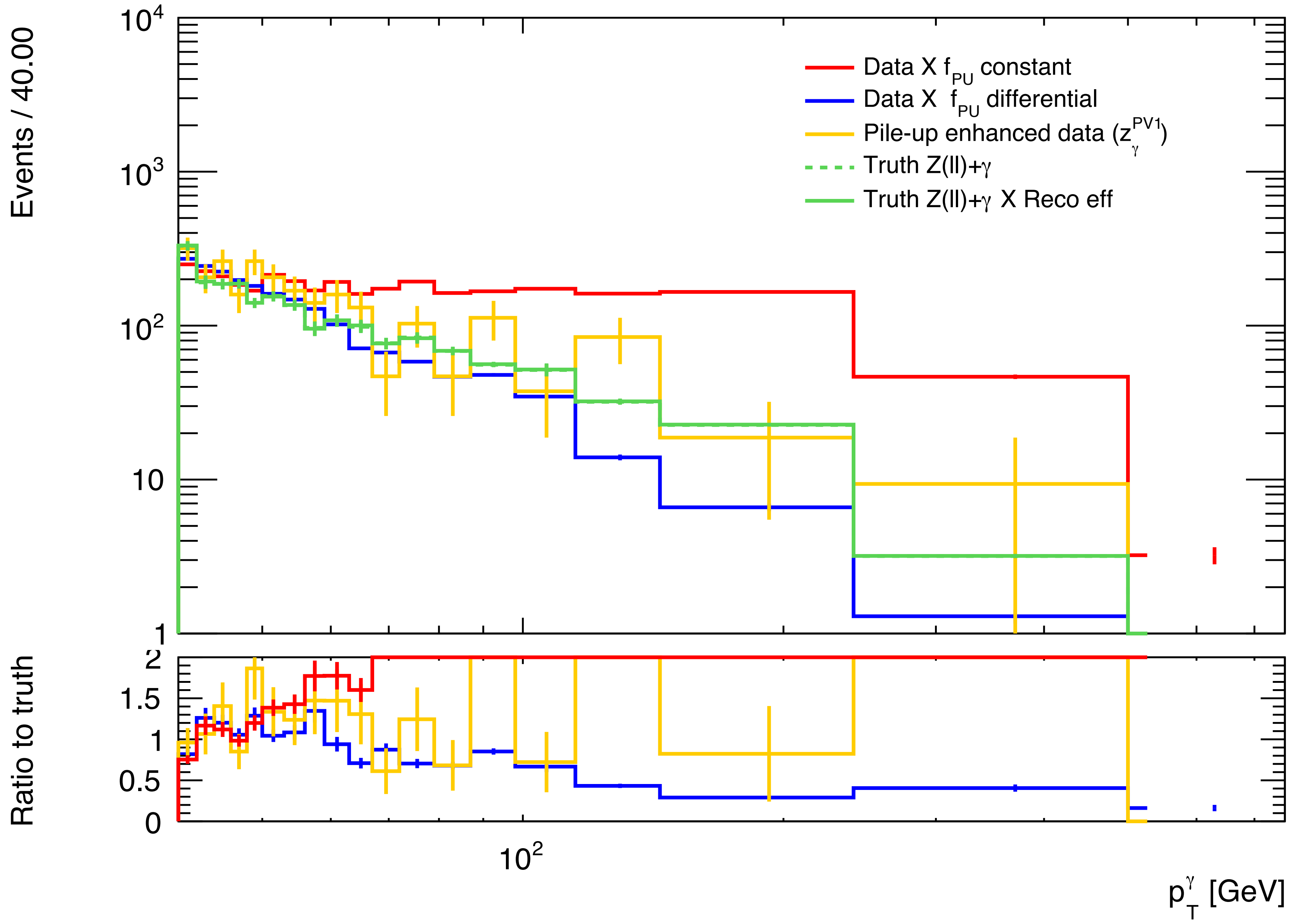
Shape

- **Shape information** is taken from **truth samples** by merging Z+jets and a single photon samples.
  - The truth samples are scaled by a jet reconstruction efficiency
  - Only jets from Z+jets sample are considered to avoid biases from JVT

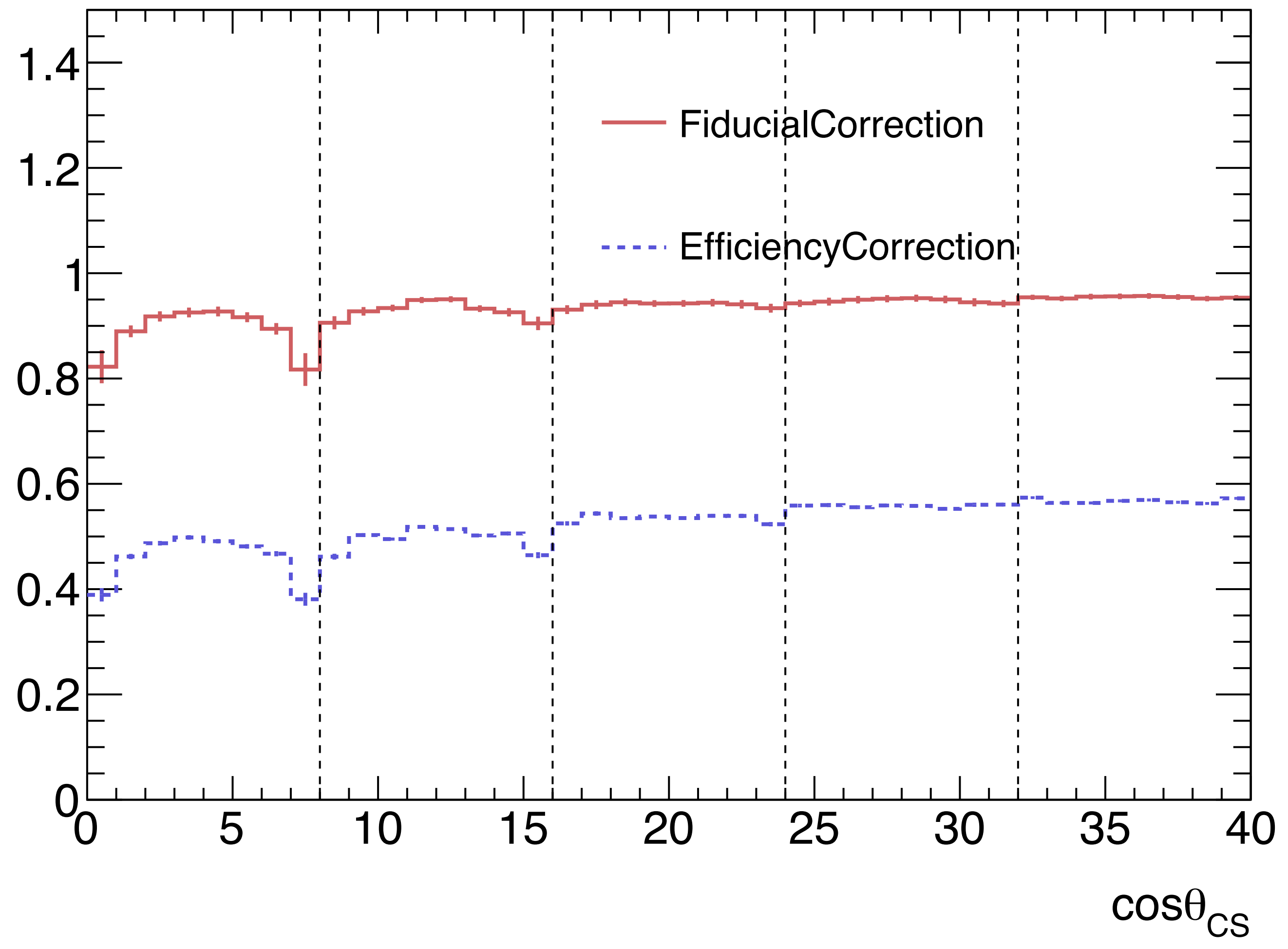
Uncertainty for pileup estimation

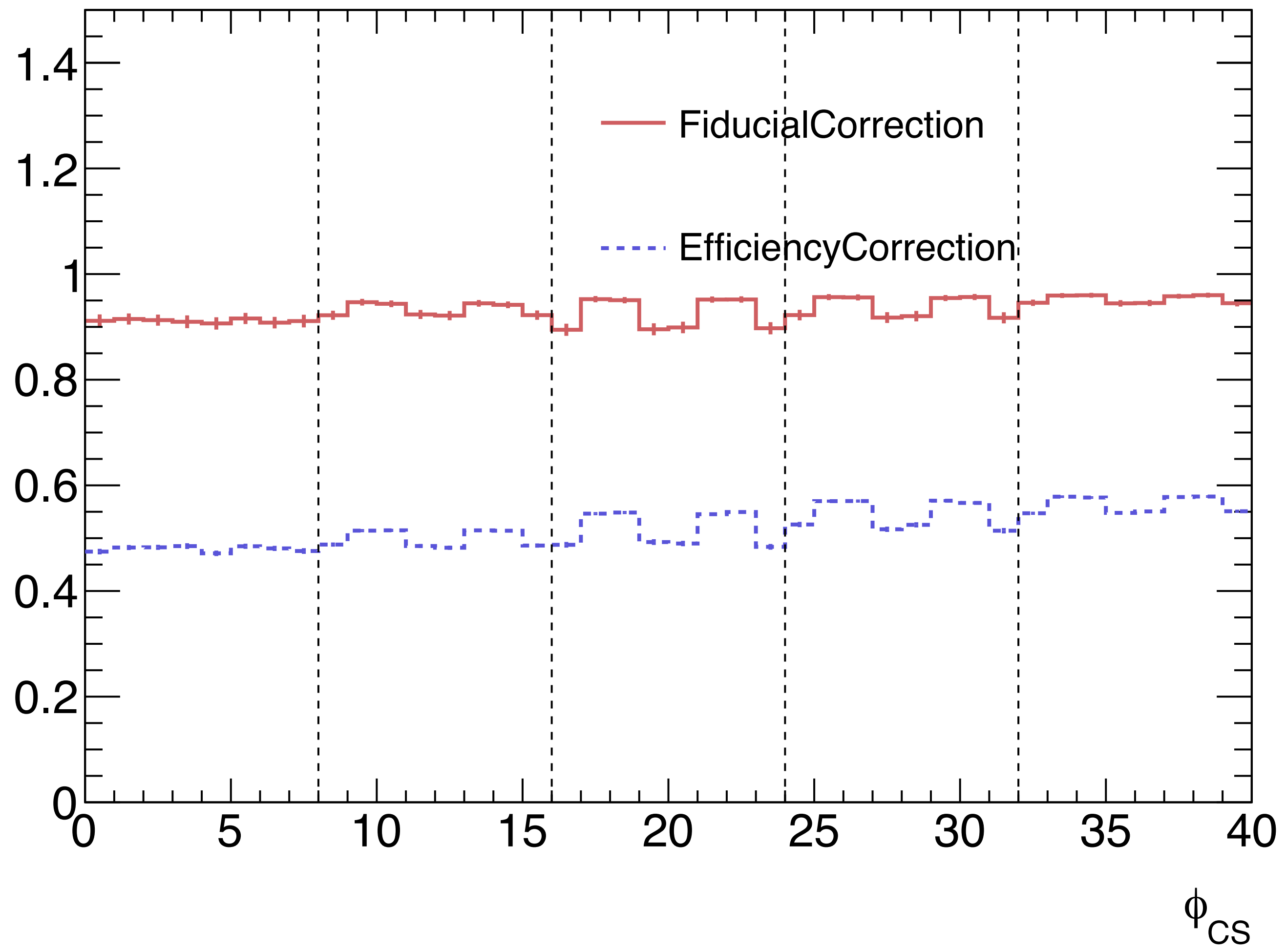
- Uncertainty is taken from difference between the **truth sample** and a Pile-up enriched sample.
  - The pile-up enriched sample is built by selecting only photons pointing to the second hardest vertex
  - For jets variables, additional uncertainty from the difference between the results when considering all jets and considering only jets associated to the Z events





Unfolding


FiducialCorrection
EfficiencyCorrection
cosθ_CS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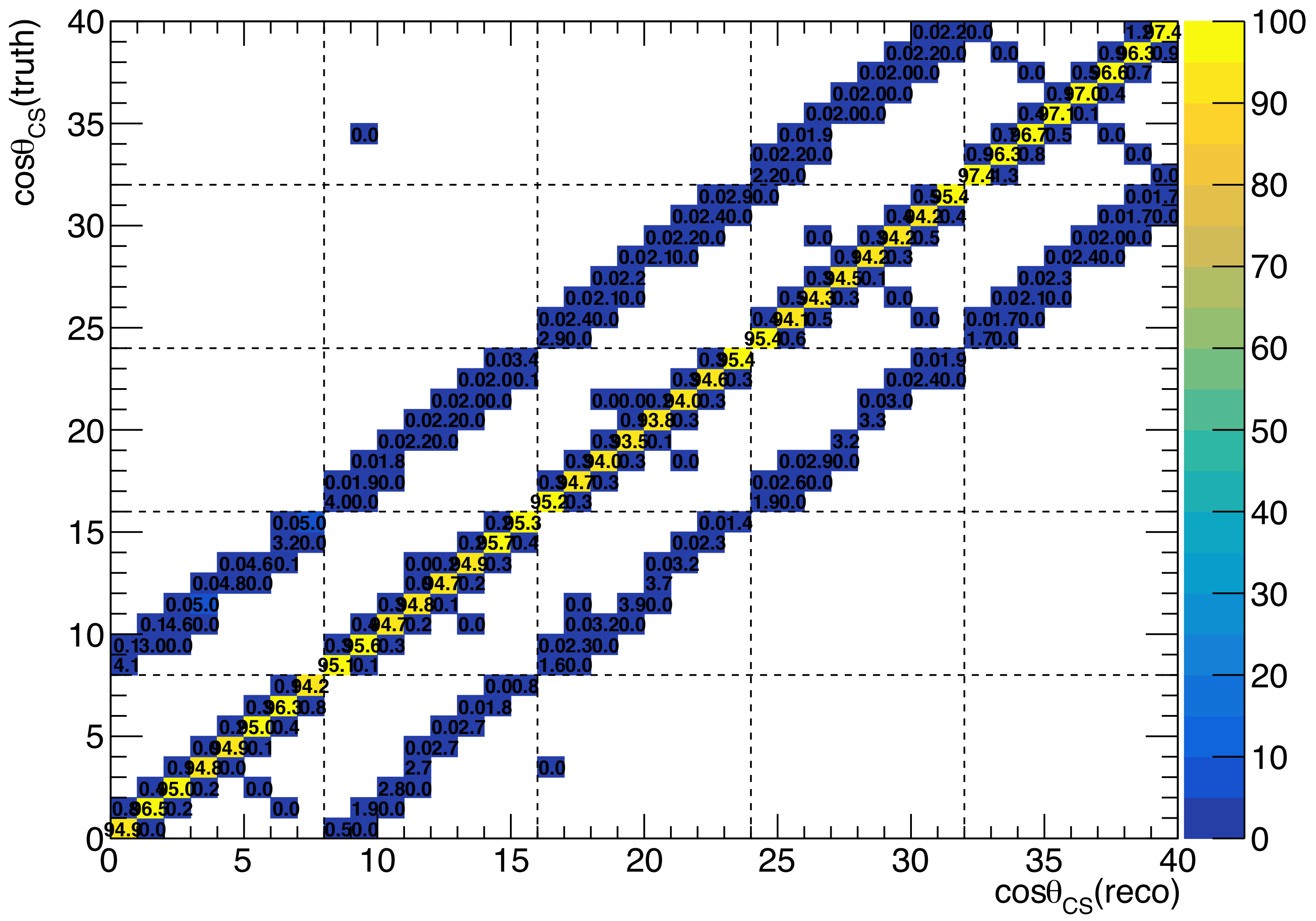
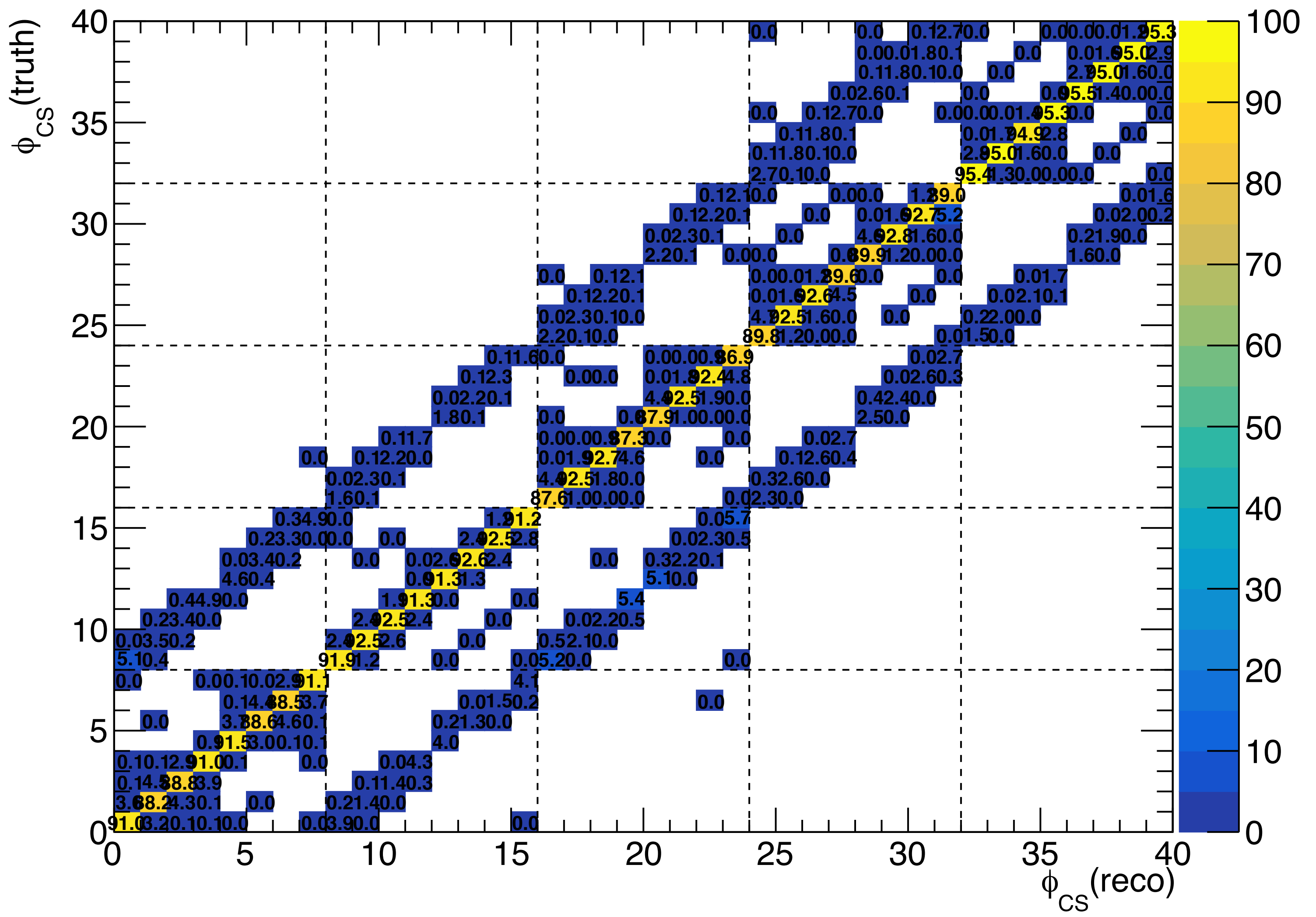
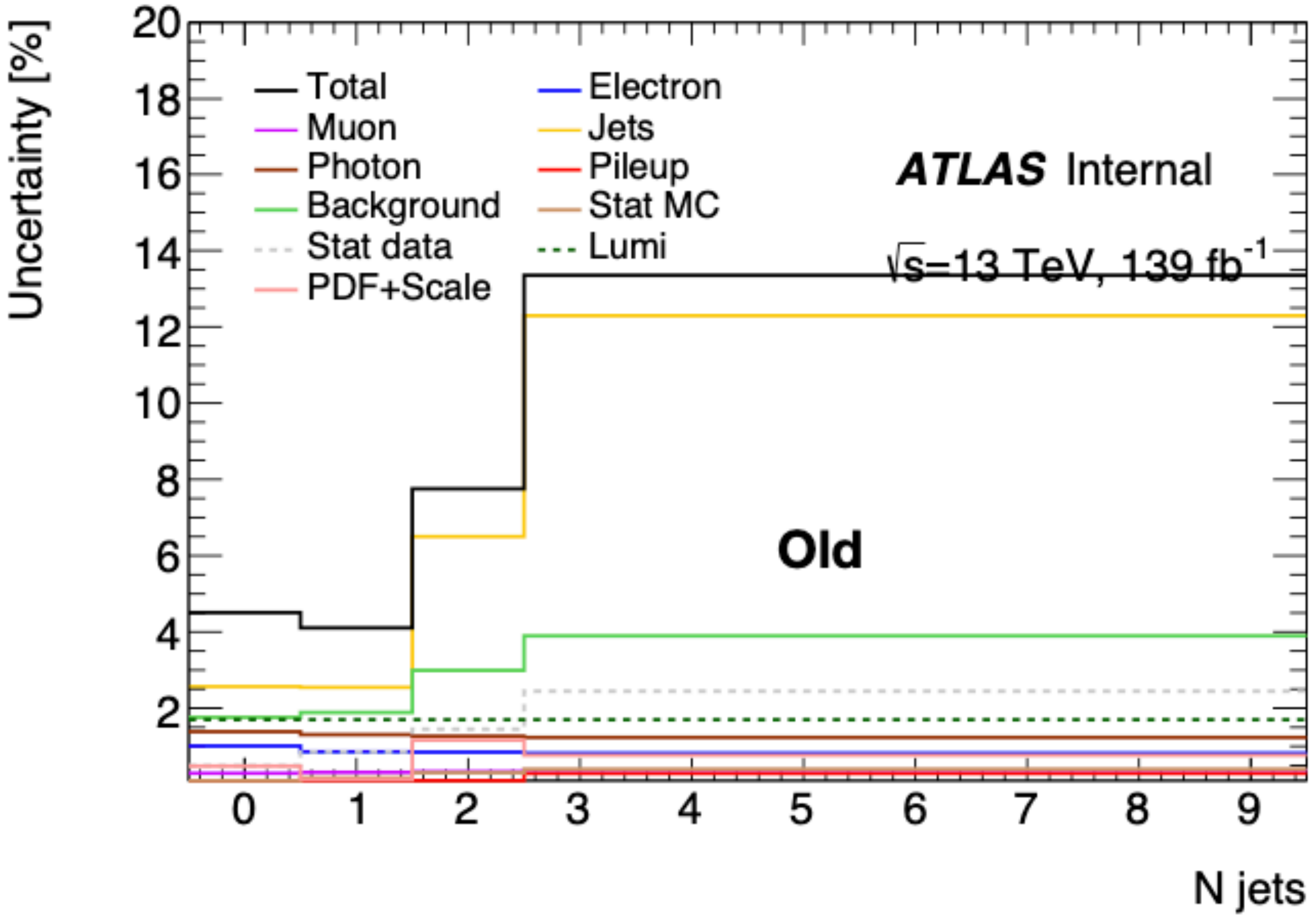
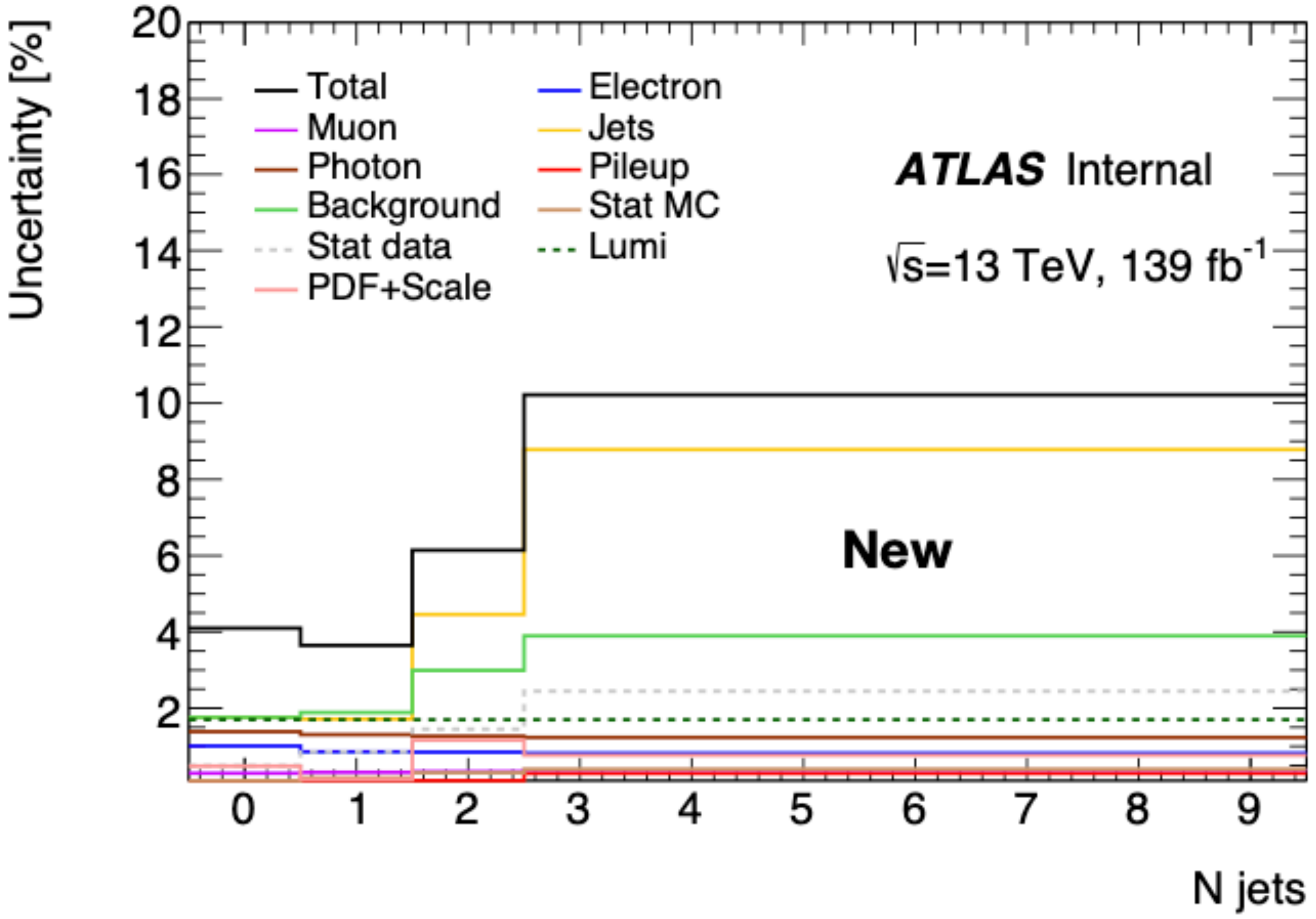
EfficiencyCorrection
φ_CS


cosθ_CS(truth)
cosθ_CS(reco)


φ_CS(truth)
φ_CS(reco)

Large reduction of JetFlavour uncertainties.





- Jet uncertainties are still dominant source of uncertainties
- Reduction is consistent with changes in gluon fraction and in its uncertainty
- RhoTopology/PUjets/EtaIntercalibrations still have a huge impact

N_{Jet}	0	1	2	> 2
Nominal Flavour Systematic [%]				
JET_Flavor_Response	0.90	0.91	2.27	4.20
JET_Flavor_Composition	1.80	1.82	4.53	8.52
New Flavour Systematic [%]				
JET_Flavor_Response	0.74	0.75	1.82	3.61
JET_Flavor_Composition	0.08	0.09	0.06	1.82

N_{Jet}	0	1	2	> 2
Systematic [%]				
JET_EffectiveNP_Modelling1	0.54	0.52	1.37	2.70
JET_EtaIntercalibration_Modelling	0.61	0.57	1.59	3.07
JET_Pileup_OffsetMu	0.29	0.24	0.73	1.59
JET_Pileup_OffsetNPV	0.47	0.45	1.18	2.33
JET_Pileup_RhoTopology	1.16	1.10	3.01	5.74
JET_Flavor_Composition	0.08	0.09	0.06	1.82
JET_Flavor_Response	0.74	0.75	1.82	3.61

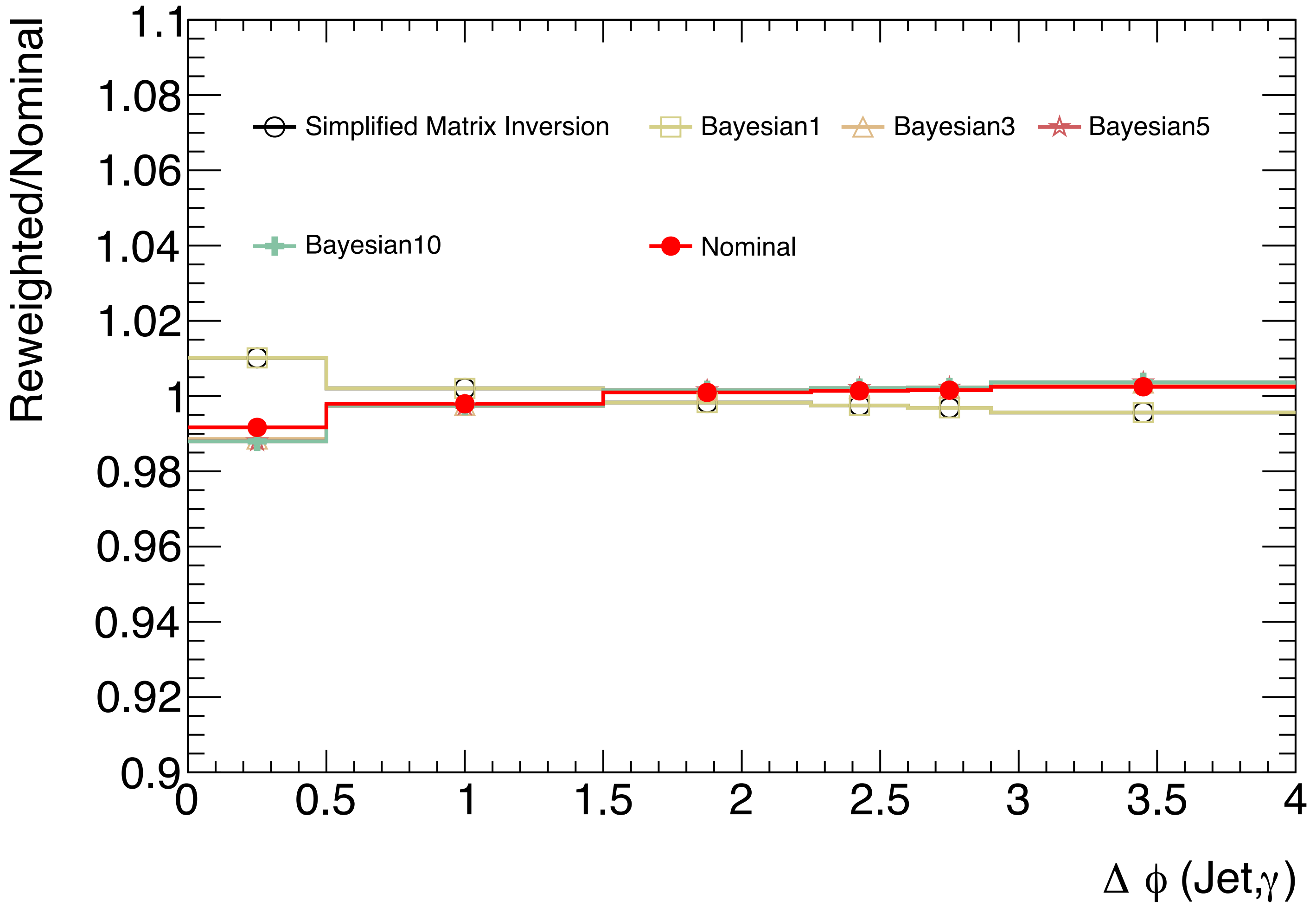
Systematic breakdown impact on the N^{Jet} distribution

$N_{\rm Jet}$	0	1	2	> 2
Total	4.10	3.65	6.14	10.22
Statistical uncertainty	0.50	0.85	1.45	2.45
Systematic uncertainty	3.70	3.11	5.72	9.77
Luminosity uncertainty	1.70	1.70	1.70	1.70
JET_BJES_Response	0.03	0.03	0.14	0.44
JET_EffectiveNP_Detector1	0.03	0.03	0.07	0.12
JET_EffectiveNP_Detector2	0.00	0.00	0.00	0.01
JET_EffectiveNP_Mixed1	0.02	0.02	0.04	0.07
JET_EffectiveNP_Mixed2	0.05	0.05	0.12	0.21
JET_EffectiveNP_Mixed3	0.02	0.03	0.06	0.08
JET_EffectiveNP_Modelling1	0.54	0.52	1.37	2.70
JET_EffectiveNP_Modelling2	0.03	0.03	0.07	0.10
JET_EffectiveNP_Modelling3	0.01	0.01	0.02	0.02
JET_EffectiveNP_Modelling4	0.00	0.00	0.01	0.02
JET_EffectiveNP_Statistical1	0.00	0.00	0.01	0.02
JET_EffectiveNP_Statistical2	0.07	0.07	0.16	0.28
JET_EffectiveNP_Statistical3	0.00	0.00	0.00	0.00
JET_EffectiveNP_Statistical4	0.00	0.00	0.00	0.00
JET_EffectiveNP_Statistical5	0.00	0.01	0.00	0.02
JET_EffectiveNP_Statistical6	0.01	0.01	0.02	0.04
JET_EtaIntercalibration_Modelling	0.61	0.57	1.59	3.07
JET_EtaIntercalibration_NonClosure_2018data	0.09	0.09	0.25	0.43
JET_EtaIntercalibration_NonClosure_highE	0.00	0.00	0.00	0.00
JET_EtaIntercalibration_NonClosure_negEta	0.02	0.03	0.02	0.04
JET_EtaIntercalibration_NonClosure_posEta	0.01	0.01	0.02	0.03
JET_EtaIntercalibration_TotalStat	0.15	0.17	0.35	0.67
JET_JER_DataVsMC_MC16	0.04	0.05	0.12	0.19
JET_JER_EffectiveNP_10	0.07	0.12	0.18	0.27
JET_JER_EffectiveNP_11	0.06	0.10	0.07	0.22
JET_JER_EffectiveNP_12restTerm	0.04	0.06	0.07	0.12
JET_JER_EffectiveNP_2	0.23	0.27	0.55	0.84
JET_JER_EffectiveNP_3	0.16	0.20	0.38	0.61
JET_JER_EffectiveNP_4	0.18	0.21	0.43	0.83
JET_JER_EffectiveNP_5	0.09	0.13	0.22	0.27
JET_JER_EffectiveNP_6	0.10	0.14	0.20	0.28
JET_JER_EffectiveNP_7	0.05	0.08	0.11	0.10
JET_JER_EffectiveNP_8	0.05	0.05	0.13	0.24
JET_JER_EffectiveNP_9	0.07	0.12	0.13	0.22
JET_JvtEfficiency	0.00	0.00	0.00	0.00
JET_Pileup_OffsetMu	0.29	0.24	0.73	1.59
JET_Pileup_OffsetNPV	0.47	0.45	1.18	2.33
JET_Pileup_PtTerm	0.05	0.06	0.13	0.24
JET_Pileup_RhoTopology	1.16	1.10	3.01	5.74
JET_PunchThrough_MC16	0.00	0.00	0.00	0.00
JET_SingleParticle_HighPt	0.00	0.00	0.00	0.00
JET_fJvtEfficiency	0.00	0.00	0.00	0.00
JET_Flavor_Composition	0.08	0.09	0.06	1.82
JET_Flavor_Response	0.74	0.75	1.82	3.61

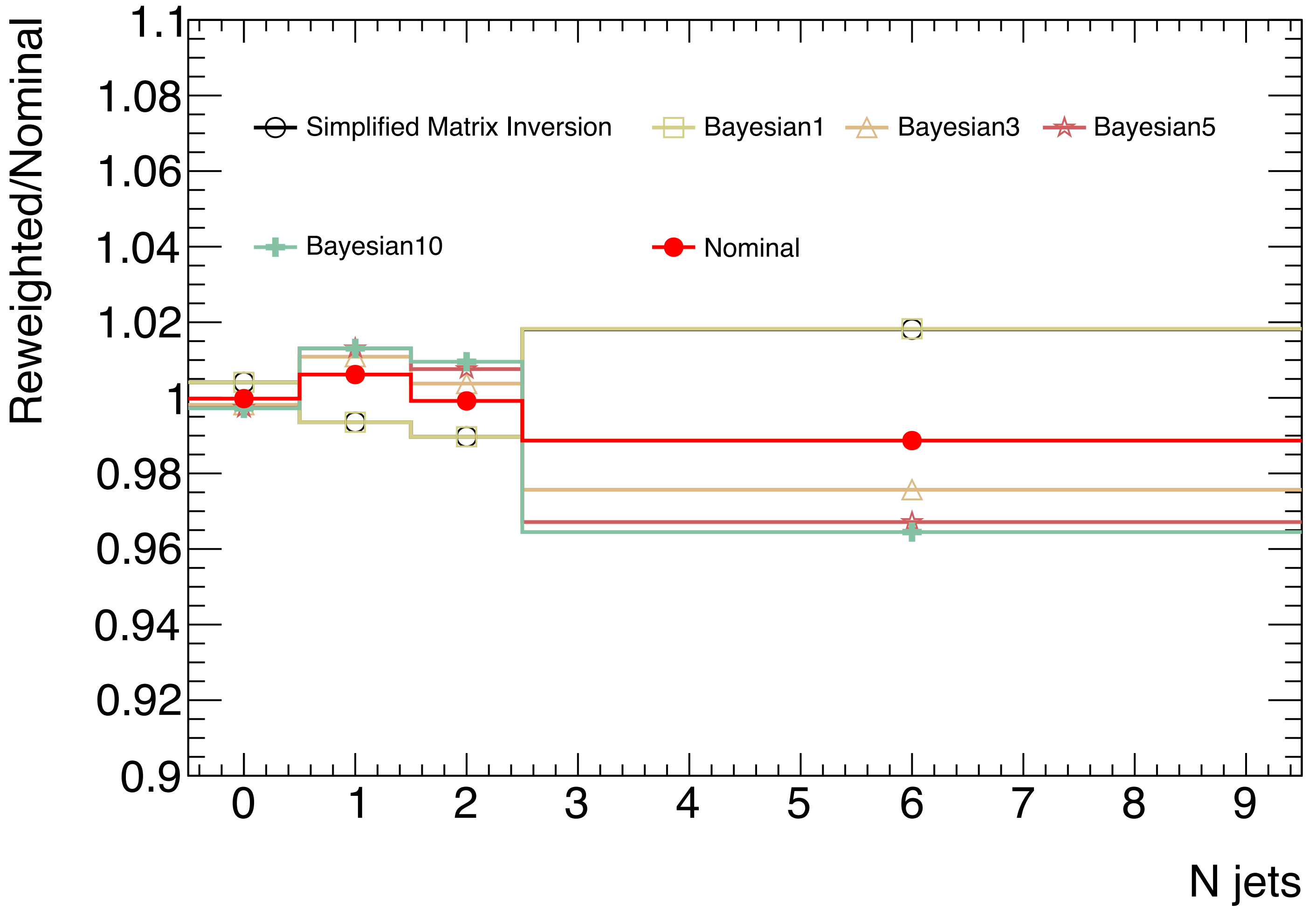
EG_RESOLUTION_ALL	0.02	0.01	0.01	0.02
EG_SCALE_ALL	0.81	0.60	0.56	0.46
EL_EFF_ID_TOTAL_1NPCOR_PLUS_UNCOR	0.60	0.60	0.62	0.67
EL_EFF_Iso_TOTAL_1NPCOR_PLUS_UNCOR	0.02	0.03	0.03	0.04
EL_EFF_Reco_TOTAL_1NPCOR_PLUS_UNCOR	0.11	0.12	0.12	0.13
MUON_EFF_ISO_STAT	0.07	0.10	0.12	0.14
MUON_EFF_ISO_SYS	0.18	0.18	0.19	0.20
MUON_EFF_RECO_STAT	0.06	0.06	0.06	0.06
MUON_EFF_RECO_STAT_LOWPT	0.02	0.02	0.00	0.02
MUON_EFF_RECO_SYS	0.19	0.21	0.23	0.26
MUON_EFF_RECO_SYS_LOWPT	0.02	0.02	0.00	0.02
MUON_EFF_TTVA_STAT	0.02	0.03	0.03	0.03
MUON_EFF_TTVA_SYS	0.03	0.03	0.04	0.04
MUON_ID	0.03	0.02	0.01	0.03
MUON_MS	0.02	0.02	0.01	0.02
MUON_SAGITTA_RESBIAS	0.04	0.03	0.02	0.01
MUON_SAGITTA_RHO	0.04	0.04	0.02	0.01
MUON_SCALE	0.08	0.06	0.08	0.06
PH_EFF_ID_Uncertainty	1.02	0.95	0.91	0.88
PH_EFF_ISO_Uncertainty	0.94	0.89	0.88	0.86
PRW_DATASF	2.05	0.77	0.21	0.29
PDF+Scale	0.48	0.13	1.16	0.77
Signal MC Stat Syst	0.10	0.17	0.31	0.40
dibosons	0.09	0.14	0.18	0.25
$WZ\gamma$	0.02	0.05	0.08	0.12
$WW\gamma$	0.04	0.06	0.09	0.12
$t\bar{t}\gamma$	0.01	0.34	1.57	3.43
$tW\gamma$	0.00	0.05	0.11	0.13
Z+jets	1.53	1.09	1.64	1.11
PU Background	0.46	0.16	0.04	0.00
Backgroud MC Stat Syst	0.72	1.48	1.94	1.44

Most important contribution are:

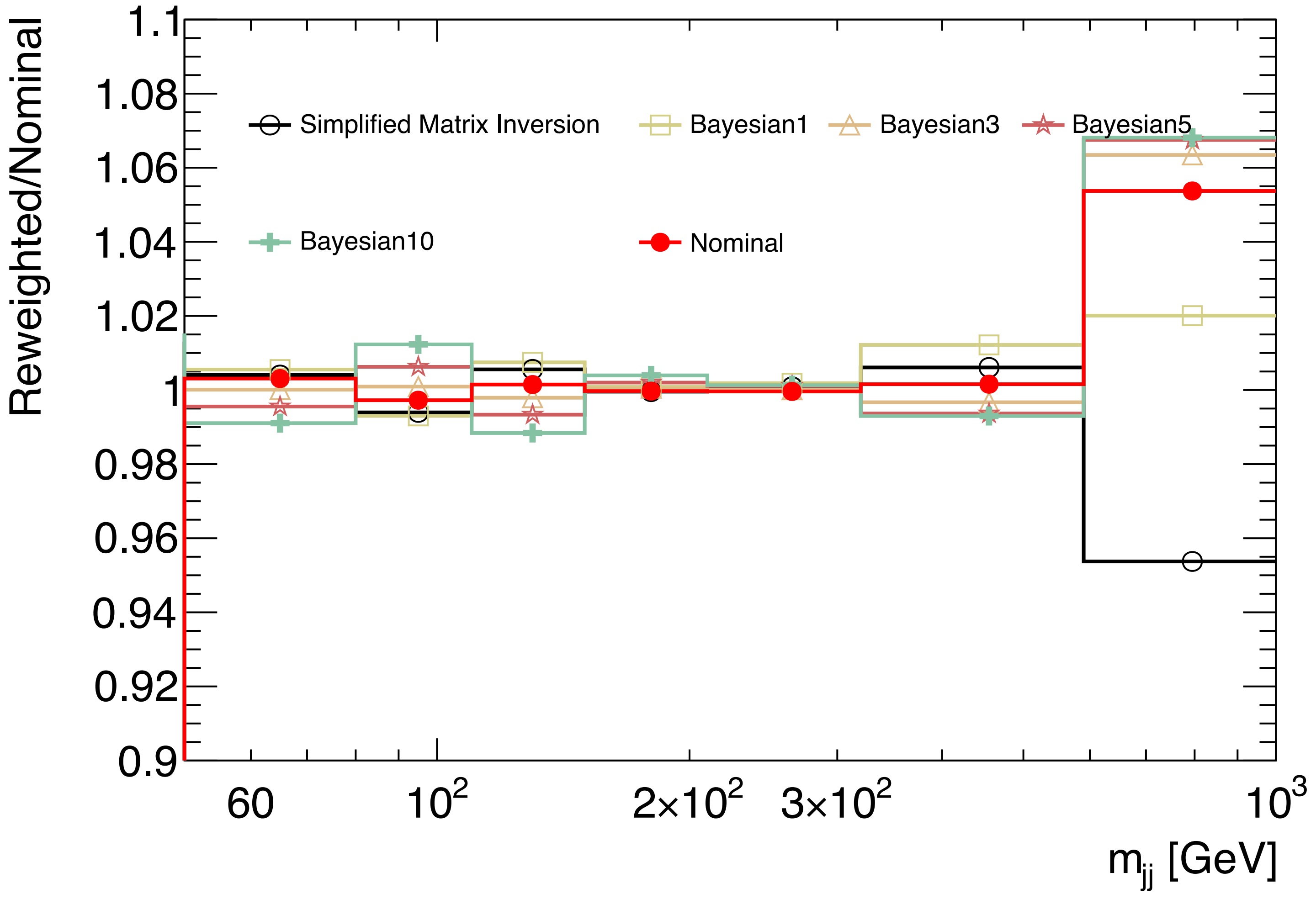
- JET_PileupRhoTopology
- JET_Flavor_Composition
- JET_Pileup_OffsetNPV
- Z+jets background
- PDF + Scale



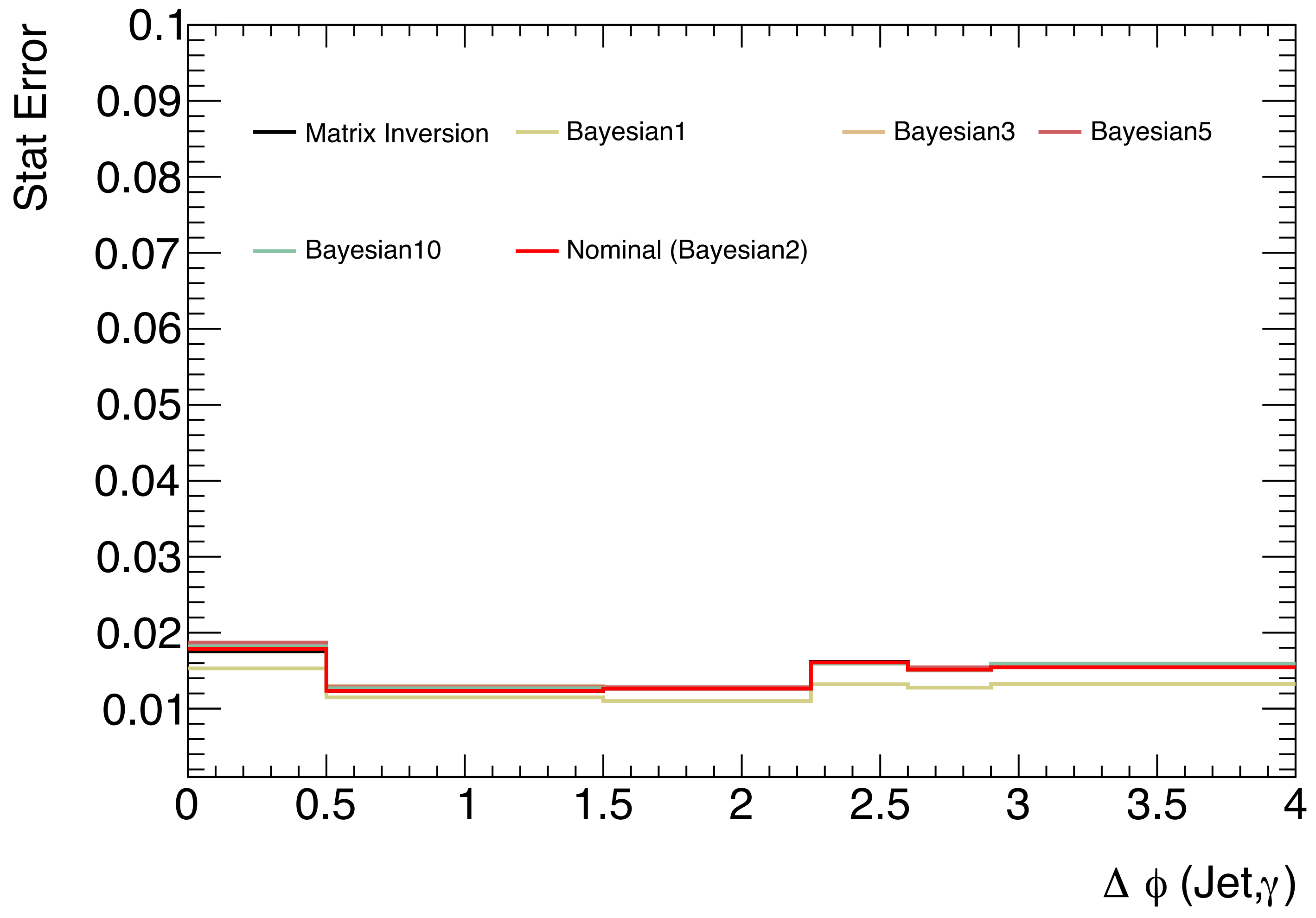
Reweighted/Nominal
Simplified Matrix Inversion
Bayesian1
Bayesian3
Bayesian5
Bayesian10
Nominal
Δ φ (Jet,γ)



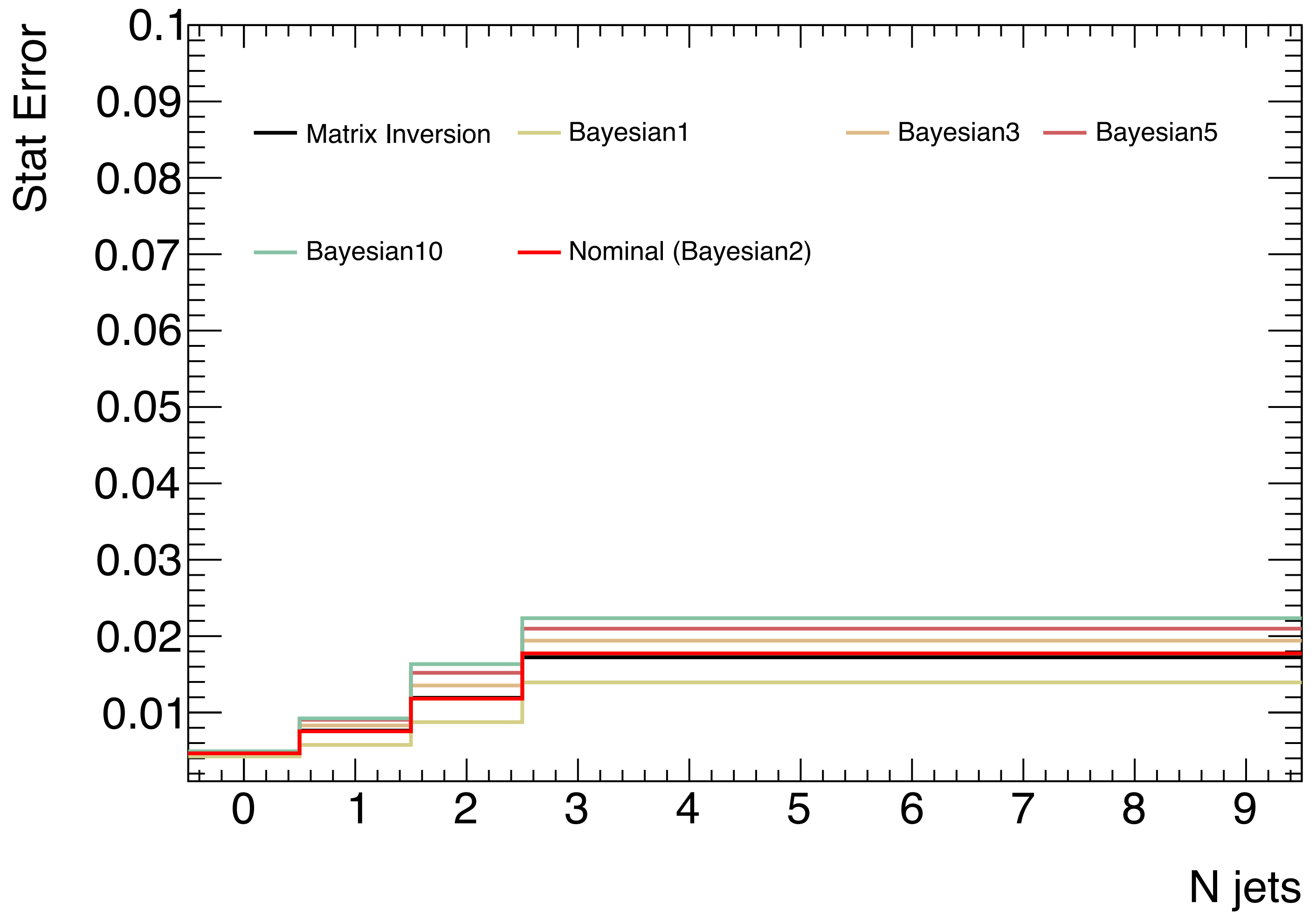
Reweighted/Nominal
Simplified Matrix Inversion
Bayesian1
Bayesian3
Bayesian5
Bayesian10
Nominal
N jets



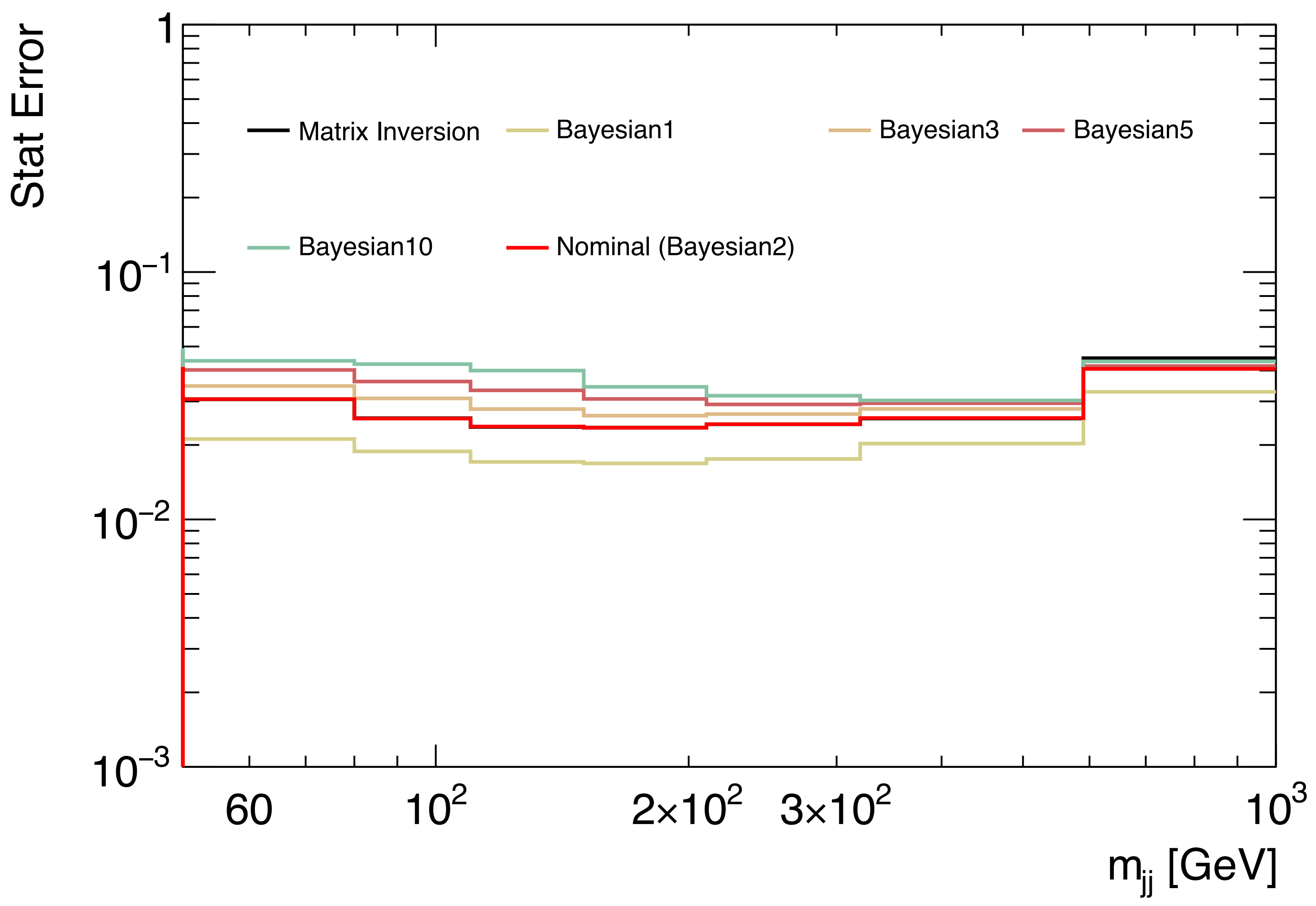
Reweighted/Nominal
Simplified Matrix Inversion
Bayesian1
Bayesian3
Bayesian5
Bayesian10
Nominal
m_jj [GeV]



Stat Error
Matrix Inversion
Bayesian1
Bayesian3
Bayesian5
Bayesian10
Nominal (Bayesian2)
Δ φ (Jet,γ)

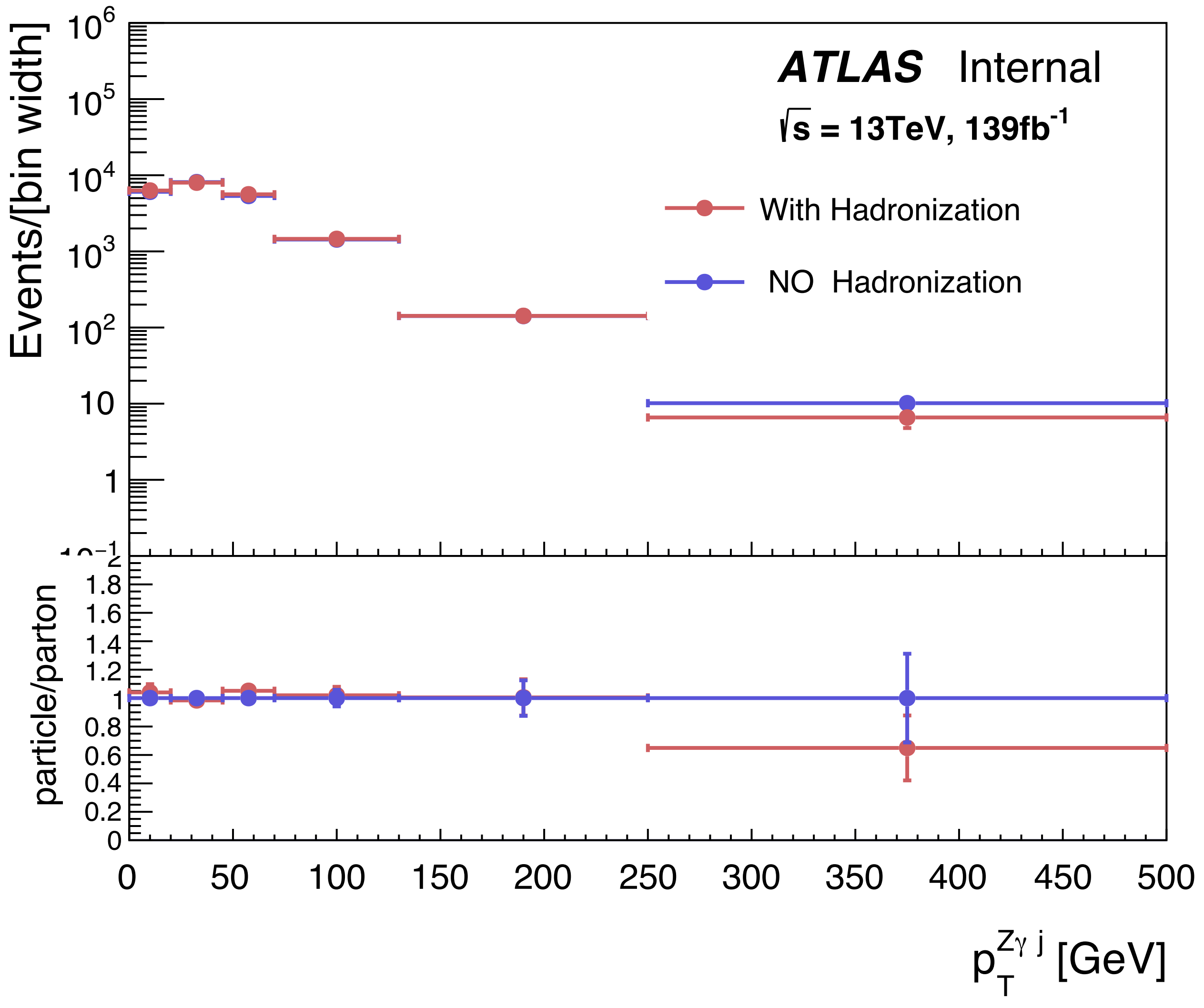


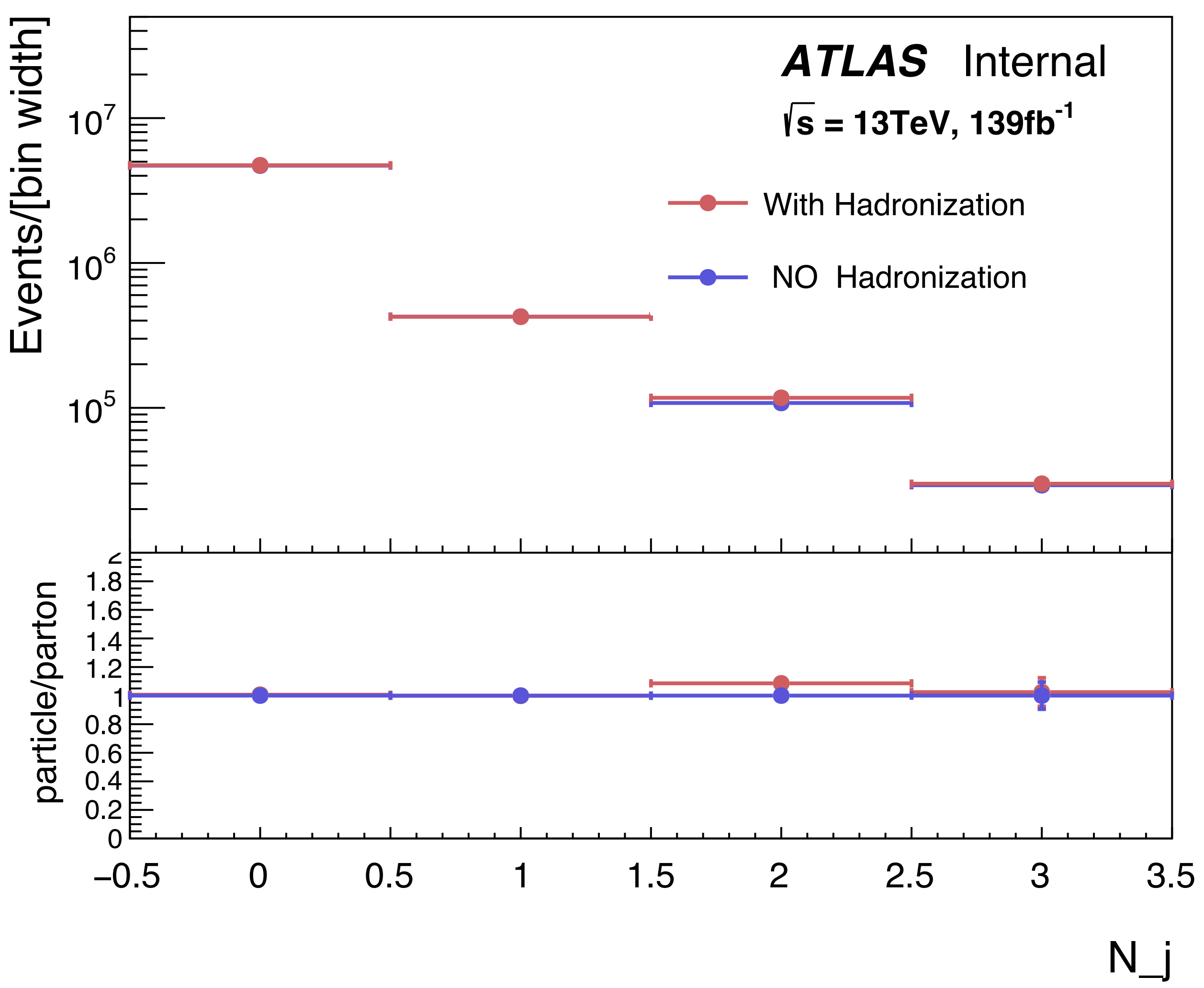
Stat Error
Matrix Inversion
Bayesian1
Bayesian3
Bayesian5
Bayesian10
Nominal (Bayesian2)
N jets

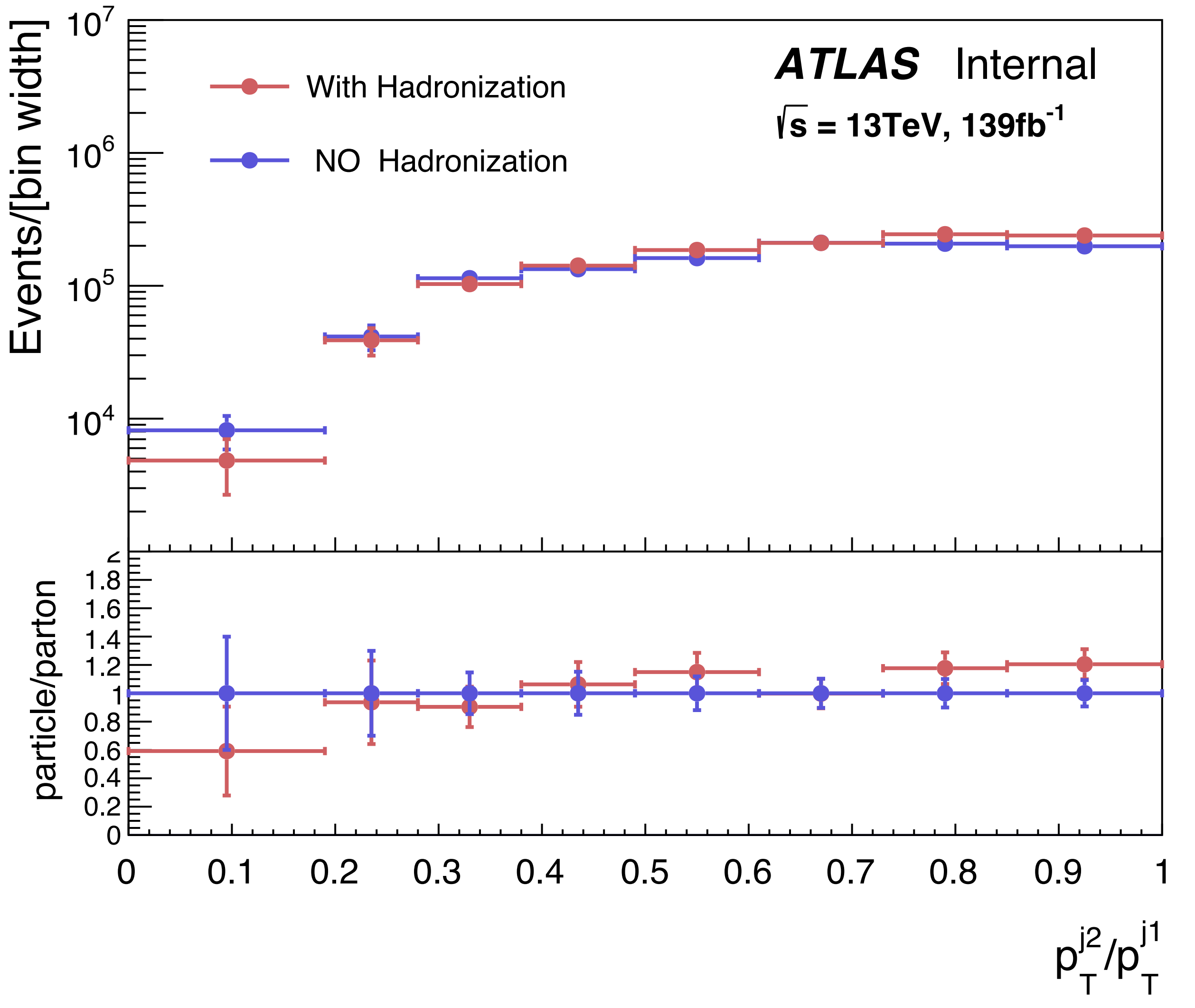


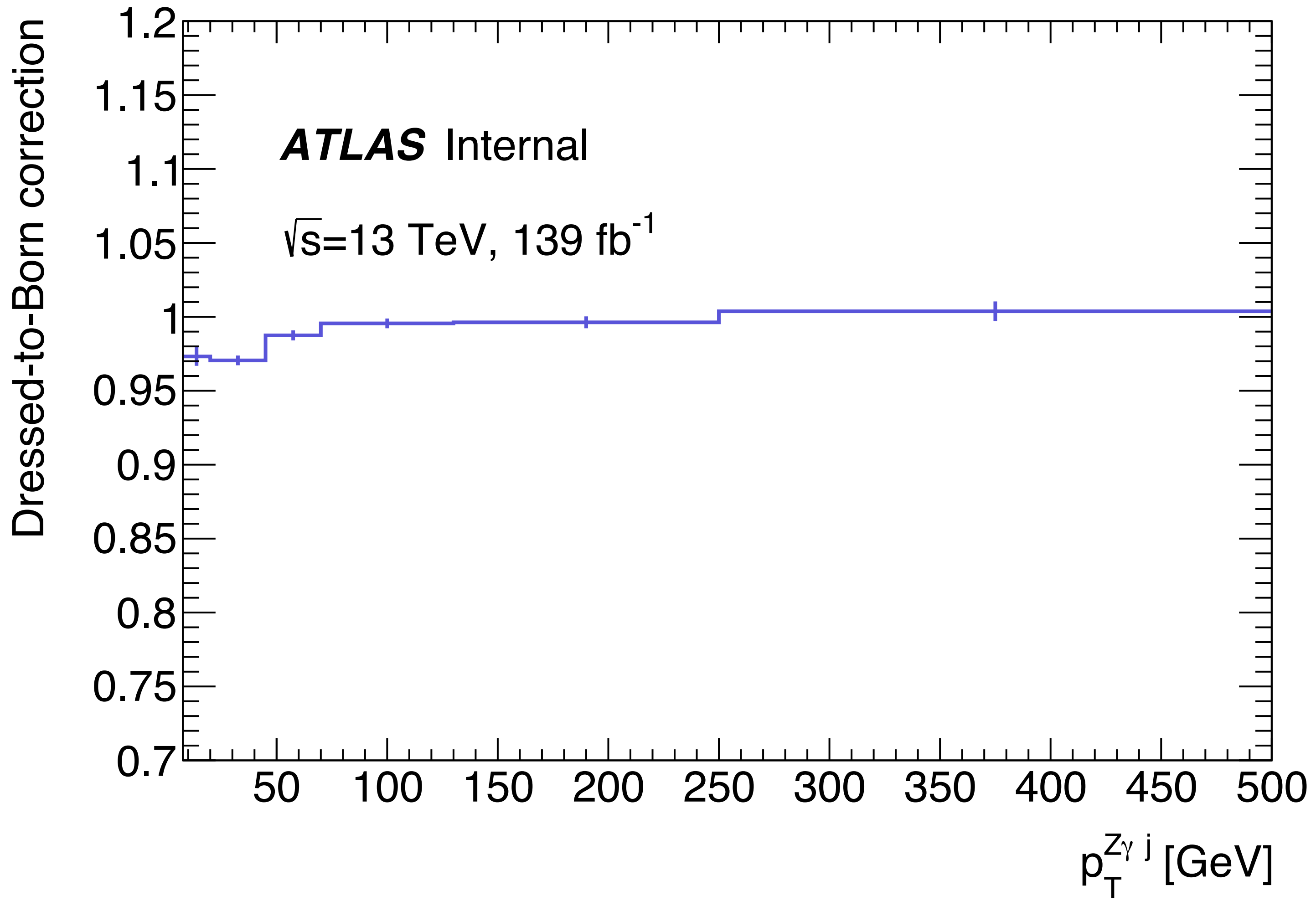
Stat Error
Matrix Inversion
Bayesian1
Bayesian3
Bayesian5
Bayesian10
Nominal (Bayesian2)
m_jj [GeV]

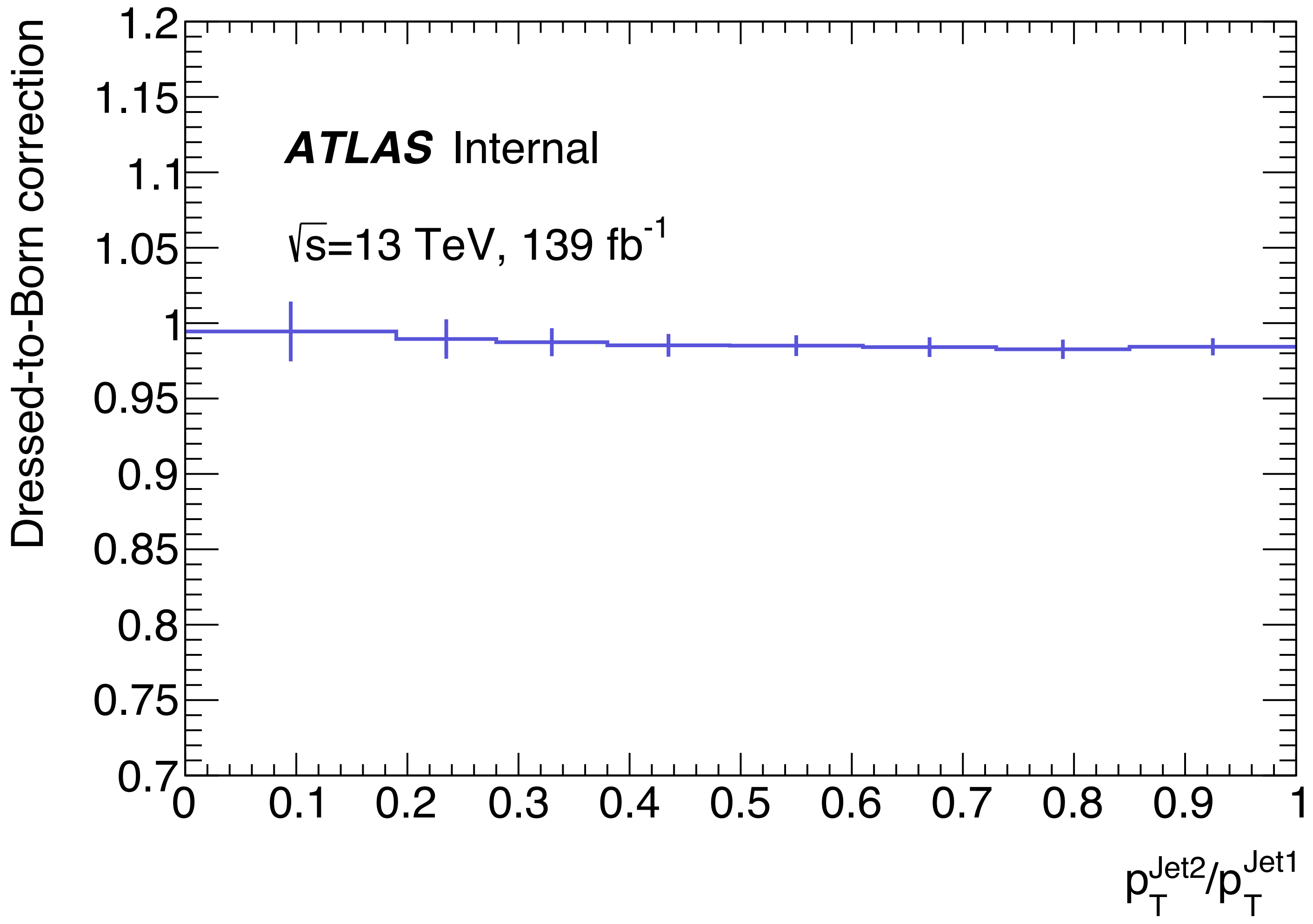
- correction for non-perturbative effects by comparing the differential cross section from samples w/o hadronization effects
- correction for born-to-particle for lepton/photon

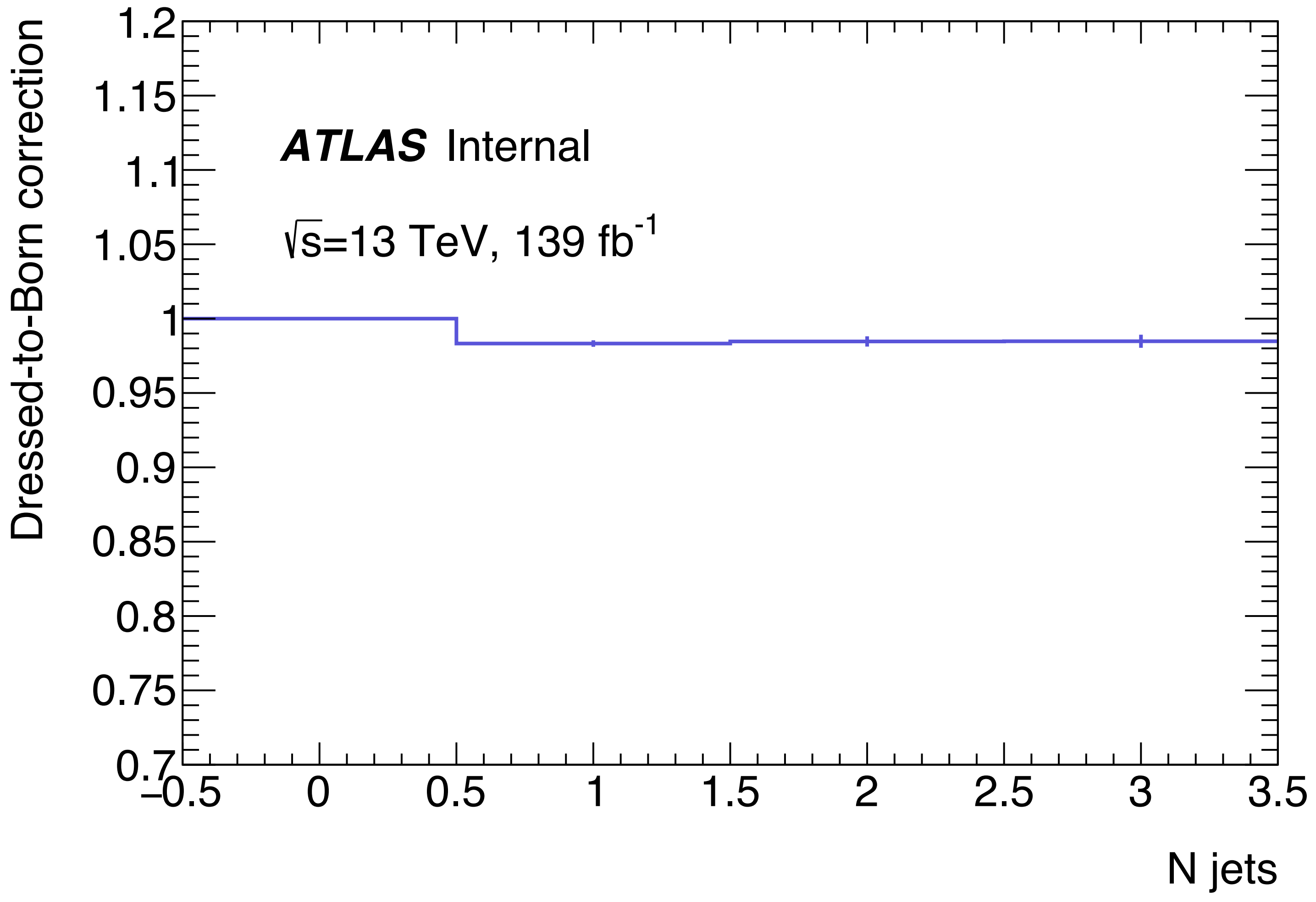












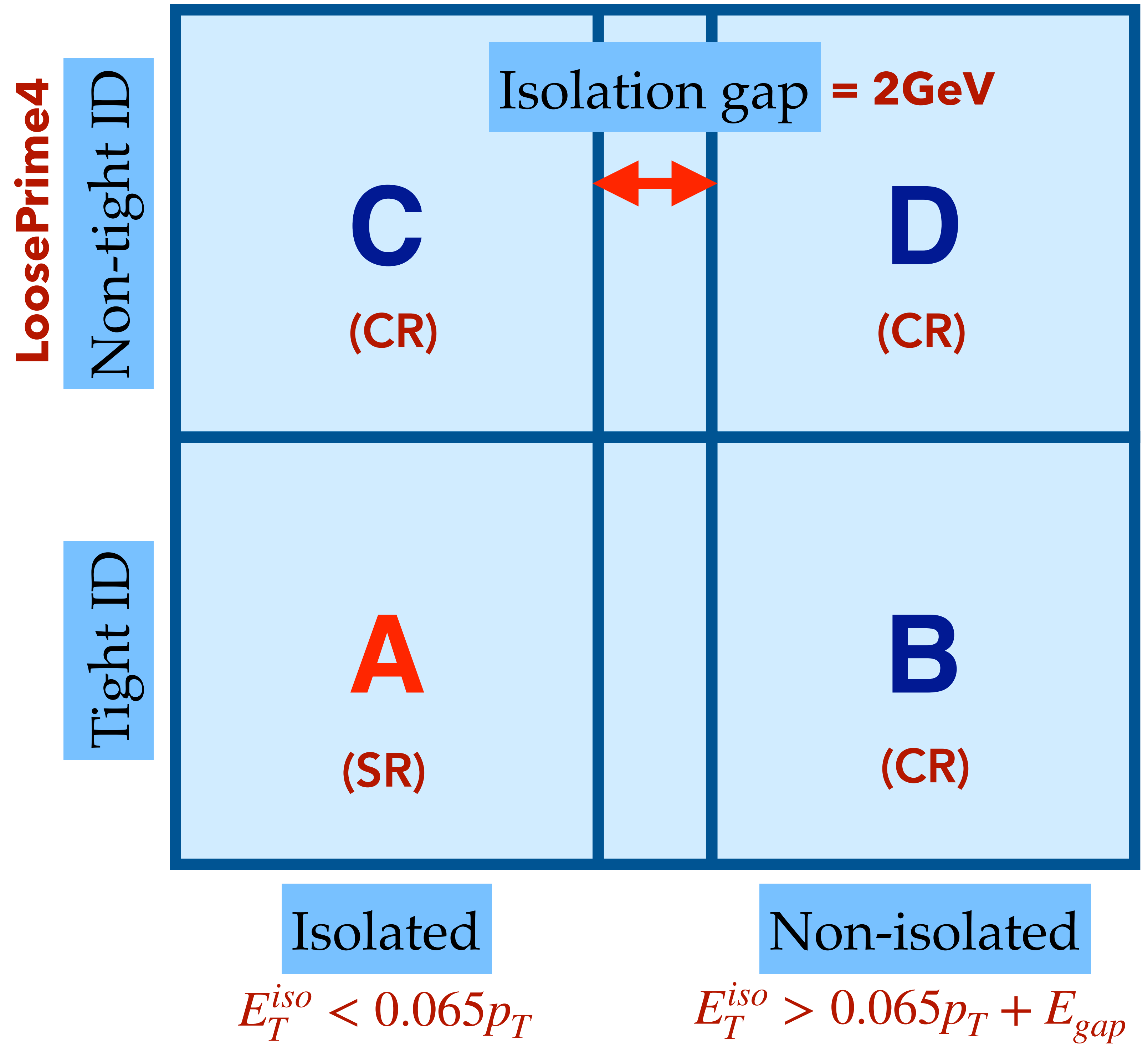
Background estimation — Z + jets

2D sideband method

- One of the jets is misidentified as a photon
- Correlation factor: $R = \dfrac{N_A^{Z+jets} \times N_D^{Z+jets}}{N_B^{Z+jets} \times N_C^{Z+jets}}$
- Signal leakage parameters: $c_B = \dfrac{N_B^{sig}}{N_A^{sig}}, c_C = \dfrac{N_C^{sig}}{N_A^{sig}}, c_D = \dfrac{N_D^{sig}}{N_A^{sig}}$
- Signal estimate: $N_A^{sig} = N_A^{data} - N_A^{bkg} - N_A^{Z+jets} = N^{sig}(N_X^{data}, N_X^{bkg}, R, c_X)$

Fake estimate: $N^{Z+jets} = (N_A^{data} - N_A^{bkg}) \times (1 - \dfrac{N_A^{sig}}{N_A^{data} - N_A^{bkg}})$

Purity



Strategy

- R and purity computed in larger bins combining both the **high statistics** and **preservation of the distribution trend**.

Uncertainties estimation for Z+jets

- **Signal leakage parameters**: Comparing Sherpa 2.2.11 with MadGraph
- **Correlation factor R**: Varying the definition of the CRs.
- **Other background**: the uncertainties of other background sources are propagated through the ABCD method.