Using γ+jets Production to Calibrate the Standard Model $Z(\rightarrow\nu\nu)$+jets Background to New Physics Processes at the LHC

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arXiv:1107.2803

TH-LPCC 2011

CERN

introduction

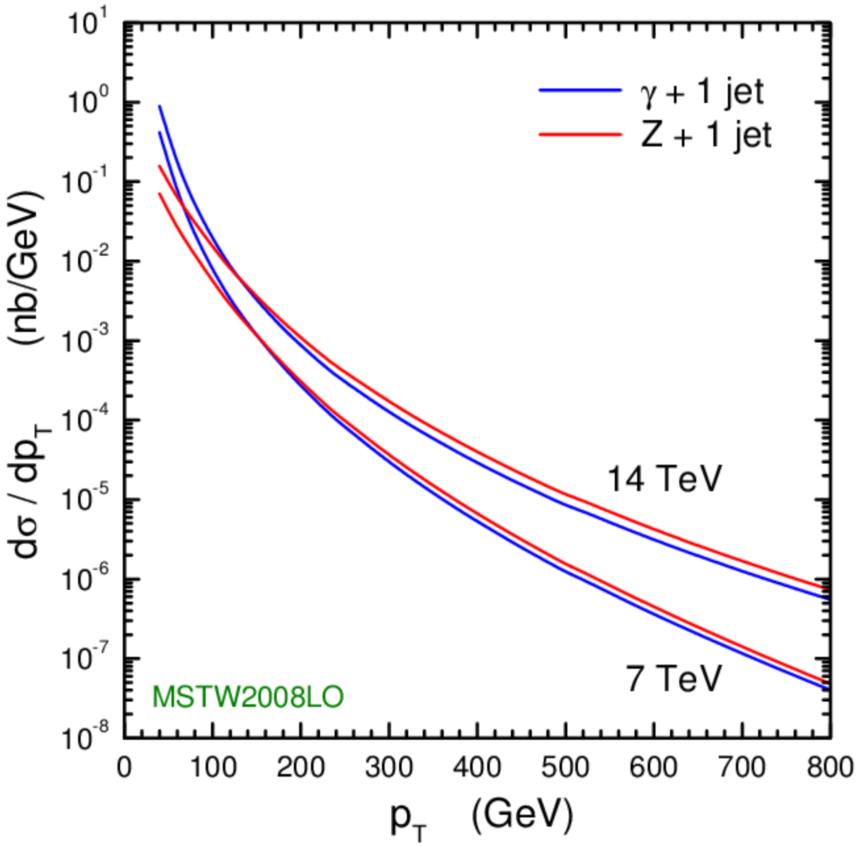
- SUSY + other BSM signals → missing transverse energy + jets
- irreducible SM background → $Z(\to\nu\nu)$ + jets
- calibrate this using *data*:
  - $Z(\to l^+ l^-)$ + jets – statistical error?
  - γ + jets – but $m_Z >> m_\gamma$?! although should be less important for $p_T >> m_Z$

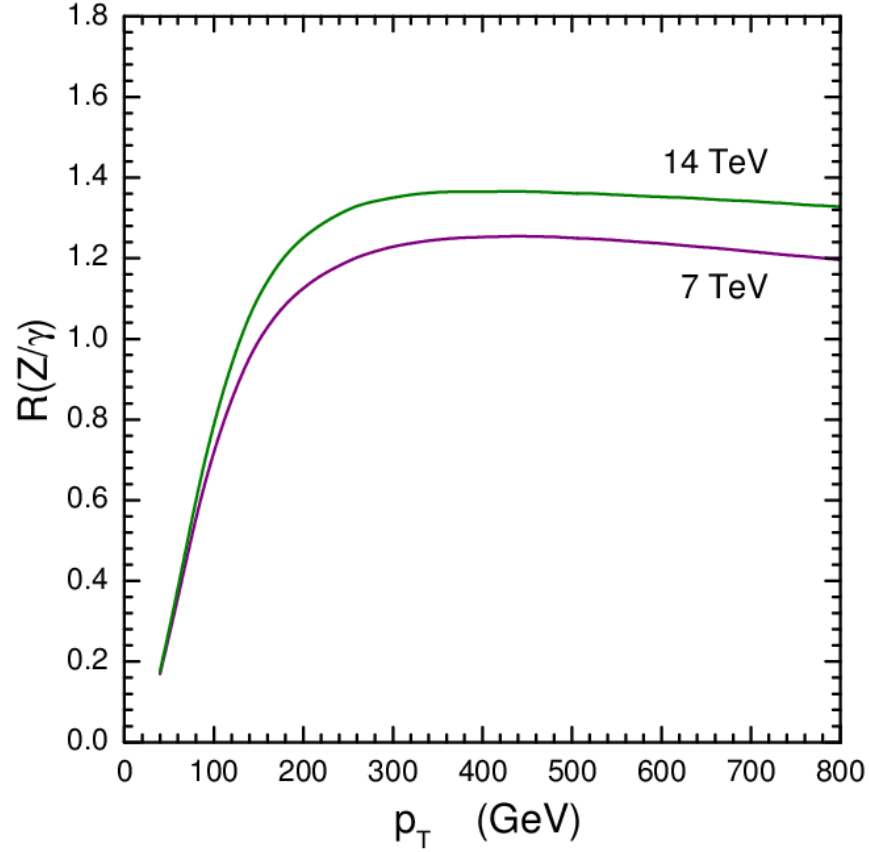
→ use γ + jets to calibrate $Z(\to\nu\nu)$ + jets at high E_T^{miss}

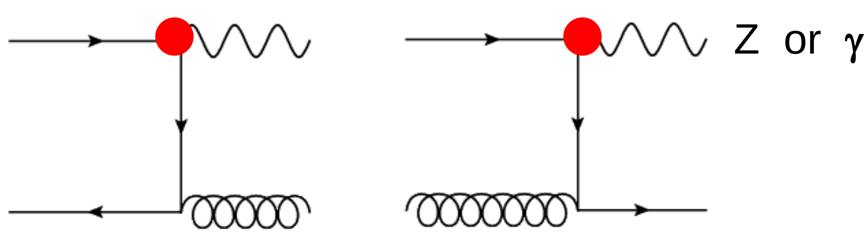
other references

- CMS:
  - "Data-driven estimation of the invisible Z background to the SUSY MET plus jets search" CMS Physics Analysis Summary SUS-08-002
  - "Search for Supersymmetry in pp Collisions at 7 TeV in Events with Jets and Missing Transverse Energy", Phys. Lett. B 698 (2011) 196
  - "Search for New Physics with Jets and Missing Transverse Momentum in pp collisions at s√ = 7 TeV" arXiv:1106.4503
- ATLAS:
  - "Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in sqrt(s) = 7 TeV proton-proton collisions", Phys. Lett. B 701 (2011)
- CDF:
  - "Observation of Vector Boson Pairs in a Hadronic Final State at the Tevatron Collider Phys. Rev. Lett. 103, 091803 (2009)

- Z. Bern, G. Diana, L.J. Dixon, F. Febres Cordero, S. Hoeche, H. Ita, D.A. Kosower, D. Maitre, K.J. Ozeren, "Driving Missing Data at Next-to-Leading Order", arXiv:1106.1423 [hep-ph]
  - a detailed parton-level study of Z,γ + 2jets at NLO pQCD, using BLACKHAT+SHERPA for NLO and ME+PS (SHERPA) for comparison





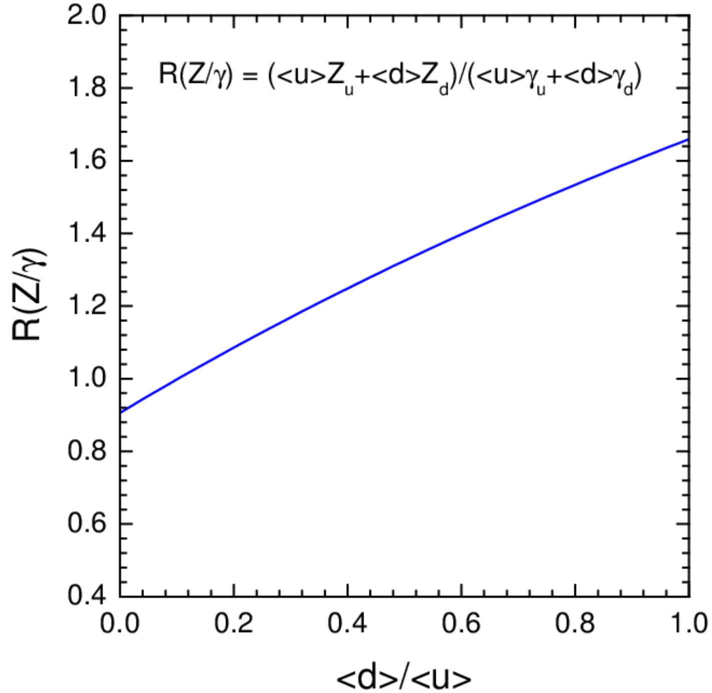


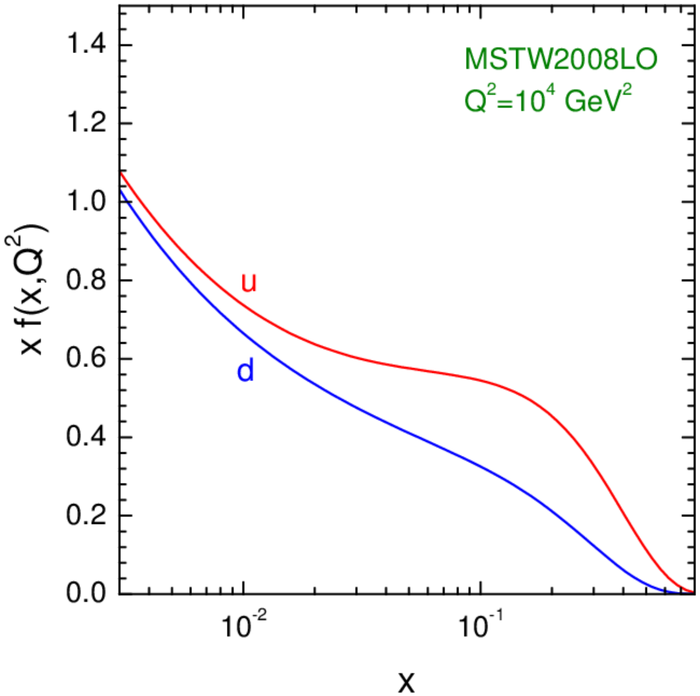
● = $-ieQ_q\gamma^\mu$ or $\frac{-ie}{2\sin\theta_W\cos\theta_W}\gamma^\mu(v_q - a_q\gamma_5)$

$$R_q = \frac{v_q^2 + a_q^2}{4\sin^2\theta_W\cos^2\theta_W Q_q^2}$$

$$R_u = 0.91, \quad R_d = 4.67$$

$$R = \frac{Z_u\langle u\rangle + Z_d\langle d\rangle}{\gamma_u\langle u\rangle + \gamma_d\langle d\rangle}$$





So R(Z/γ) depends weakly on pdfs:

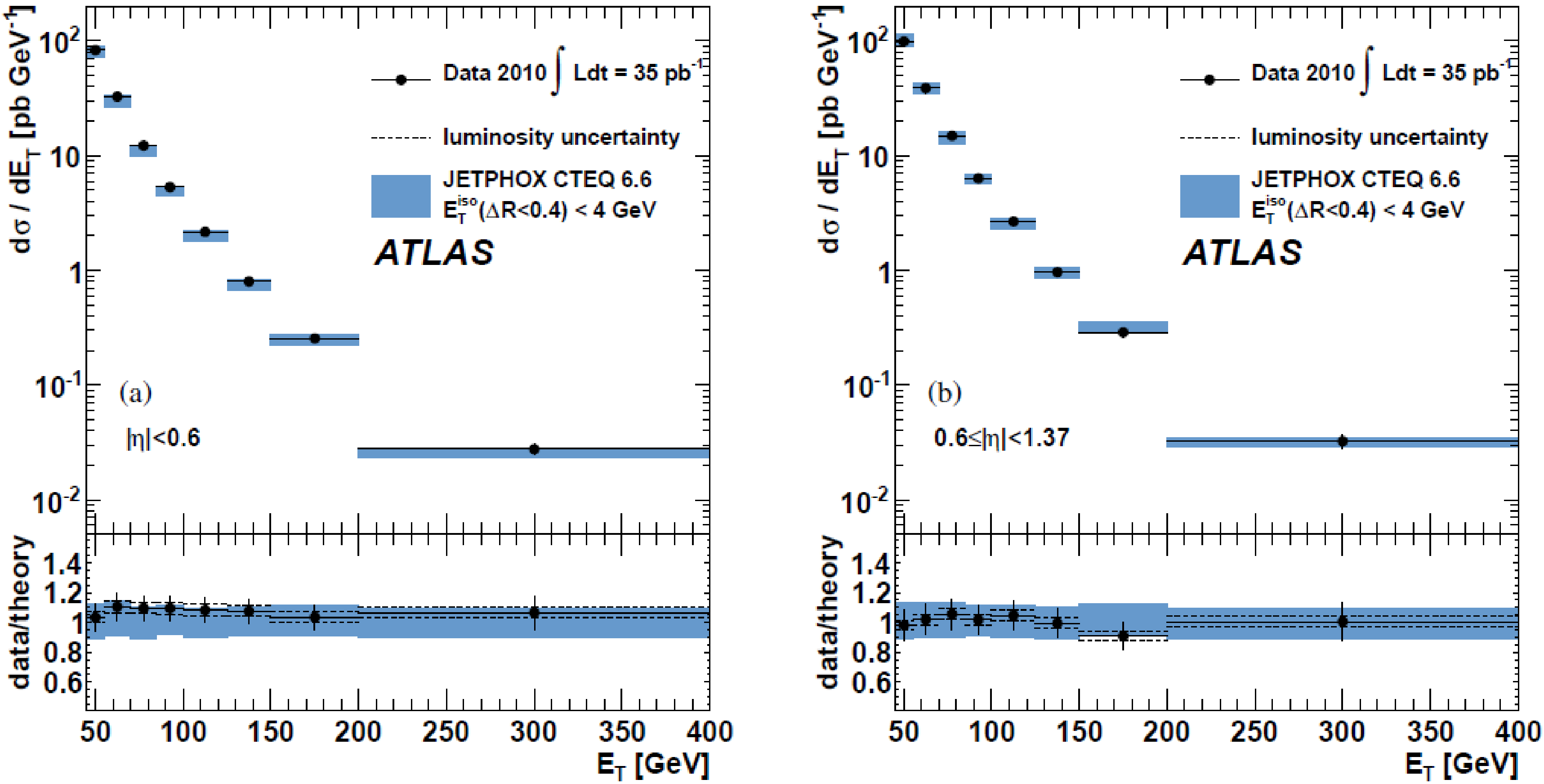
$\sqrt{s} \uparrow \Rightarrow x \downarrow \Rightarrow d/u \uparrow \Rightarrow R \uparrow$

$p_T \to p_T^{max} \Rightarrow x \uparrow \Rightarrow d/u \downarrow \Rightarrow R \downarrow$

Master formula:

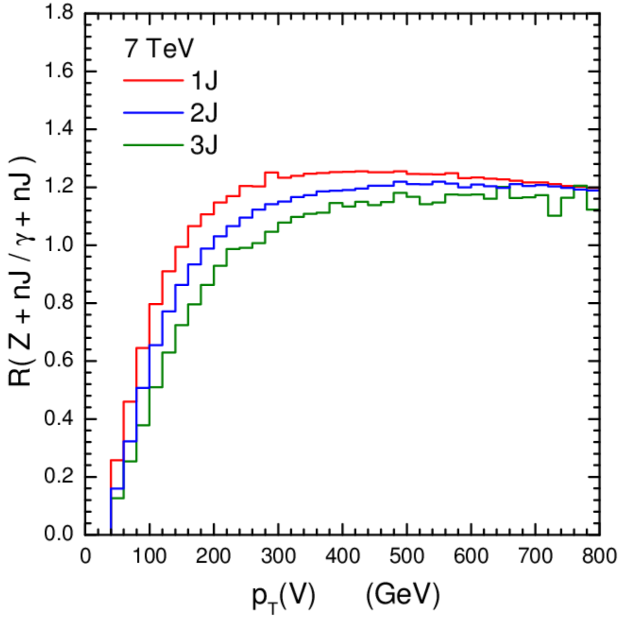
$$\frac{d\sigma(Z(\to \nu\bar{\nu}) + X)}{dE_T^{\text{miss}}} = B(Z \to \nu\bar{\nu}) \cdot \underbrace{R(Z/\gamma) \cdot \mathcal{A}^{-1}}_{\text{study theoretical and experimental uncertainties}} \cdot \frac{d\sigma^{\text{meas.}}(\gamma + X)}{dE_T^{\gamma}}$$

ATLAS, arXiv:1108.0253



Note: systematic error ~ 5%-10%, decreasing slightly with E_T

variation of R(Z/γ) with number of jets

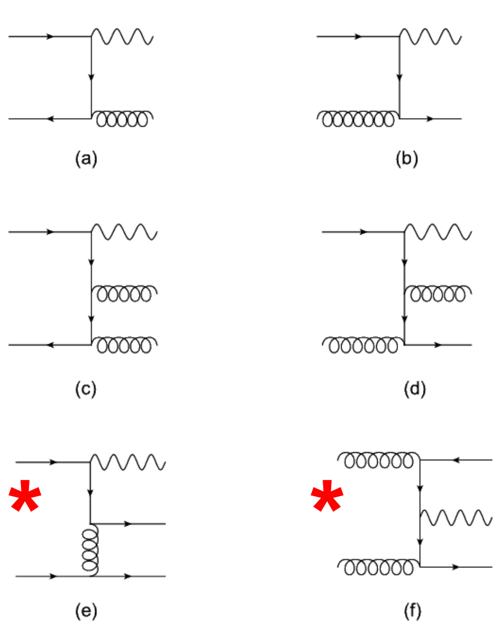


Because:

more jets ⇒ higher ΣE_T ⇒ higher x

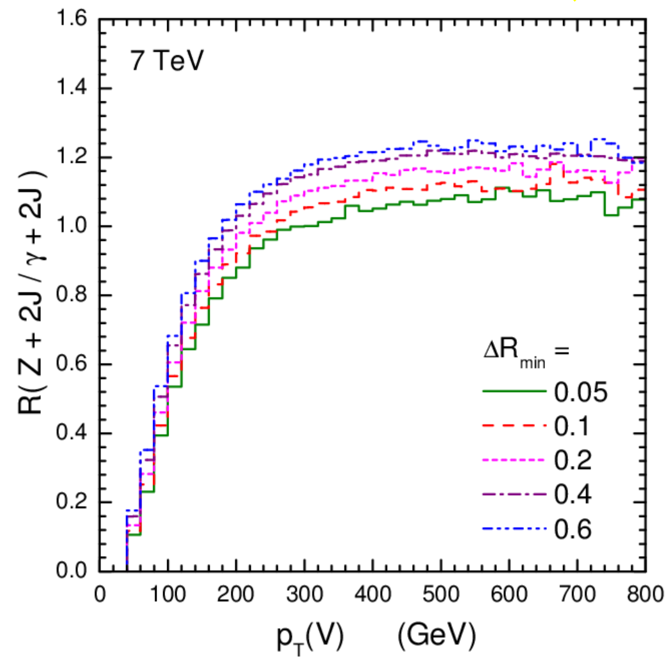
for $n_{jet} > 1$, gg and qq diagrams (*) with different dependence on couplings

for $n_{jet} > 1$, collinear singularity q→qγ (‘photon fragmentation’ contribution, depends on isolation cut/criterion)



Note: these are parton-, tree-level ME calculations using **GAMBOS**, a variant of **VECBOS** (Giele et al) with Z→γ

jets defined by p_{Tj}> 40 GeV, $|\eta_j| < 2.5$, $\Delta R(V,j) > 0.4$, $\Delta R(j,j) > 0.4$



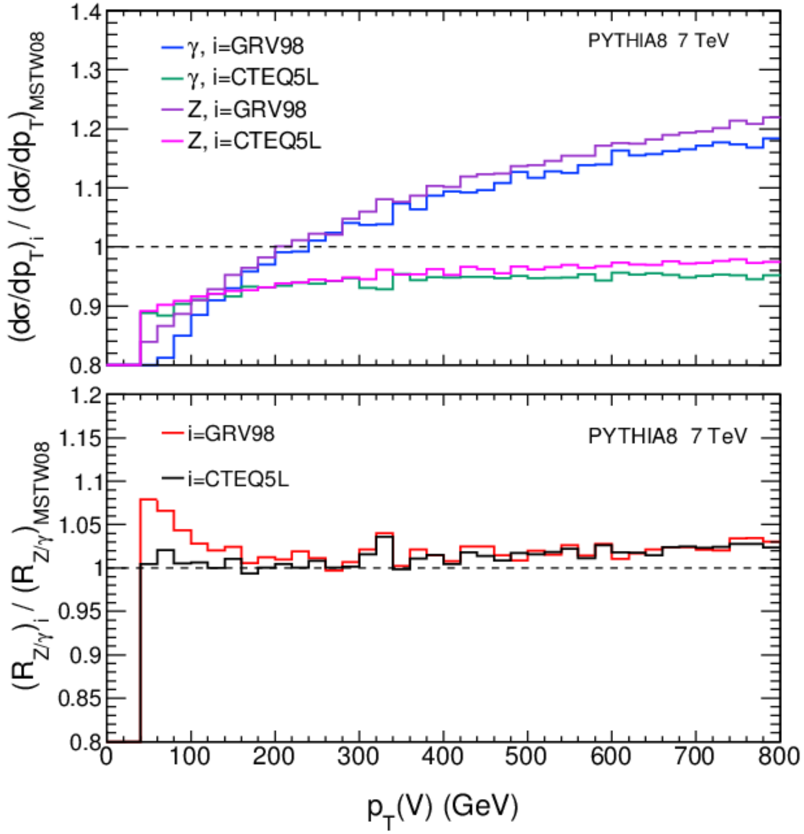
uncertainties in the R(Z/γ) calculation

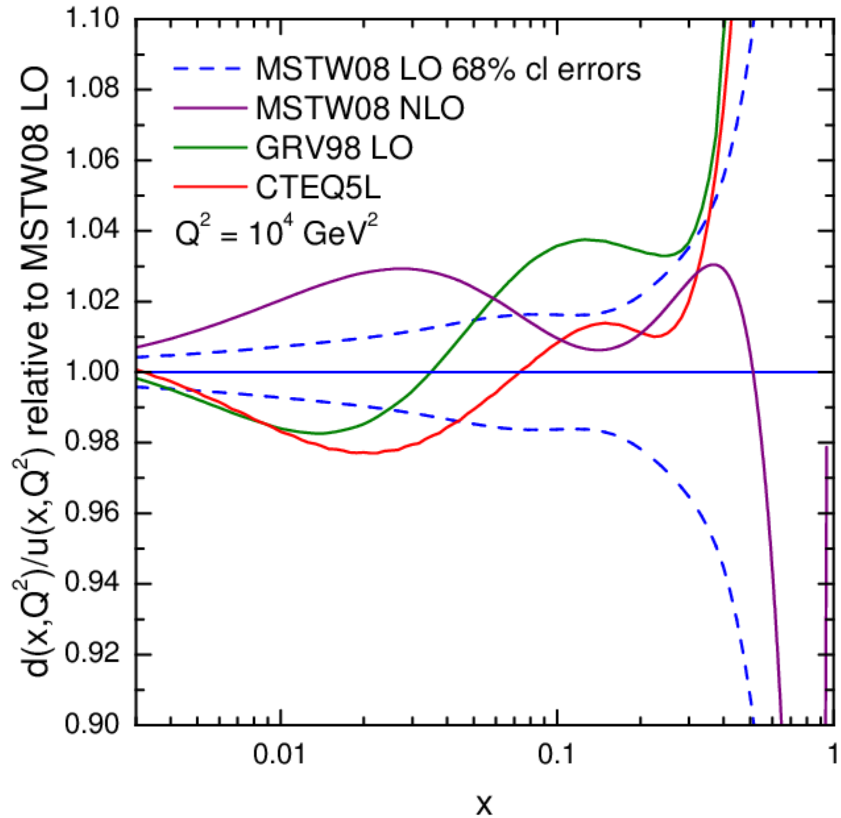
- PDFs: directly related to uncertainty in d/u (see over)
  → ±4% on the ratio at high p_T

- variation of scales: μ_R and μ_F (note: this is a LO analysis)
  - only differences are from scales like $p_T^2+m_V^2$, but these diminish at high p_T → ±3% on the ratio at high p_T
  - but no substitute for a full NLO pQCD treatment (e.g. Bern et al.)

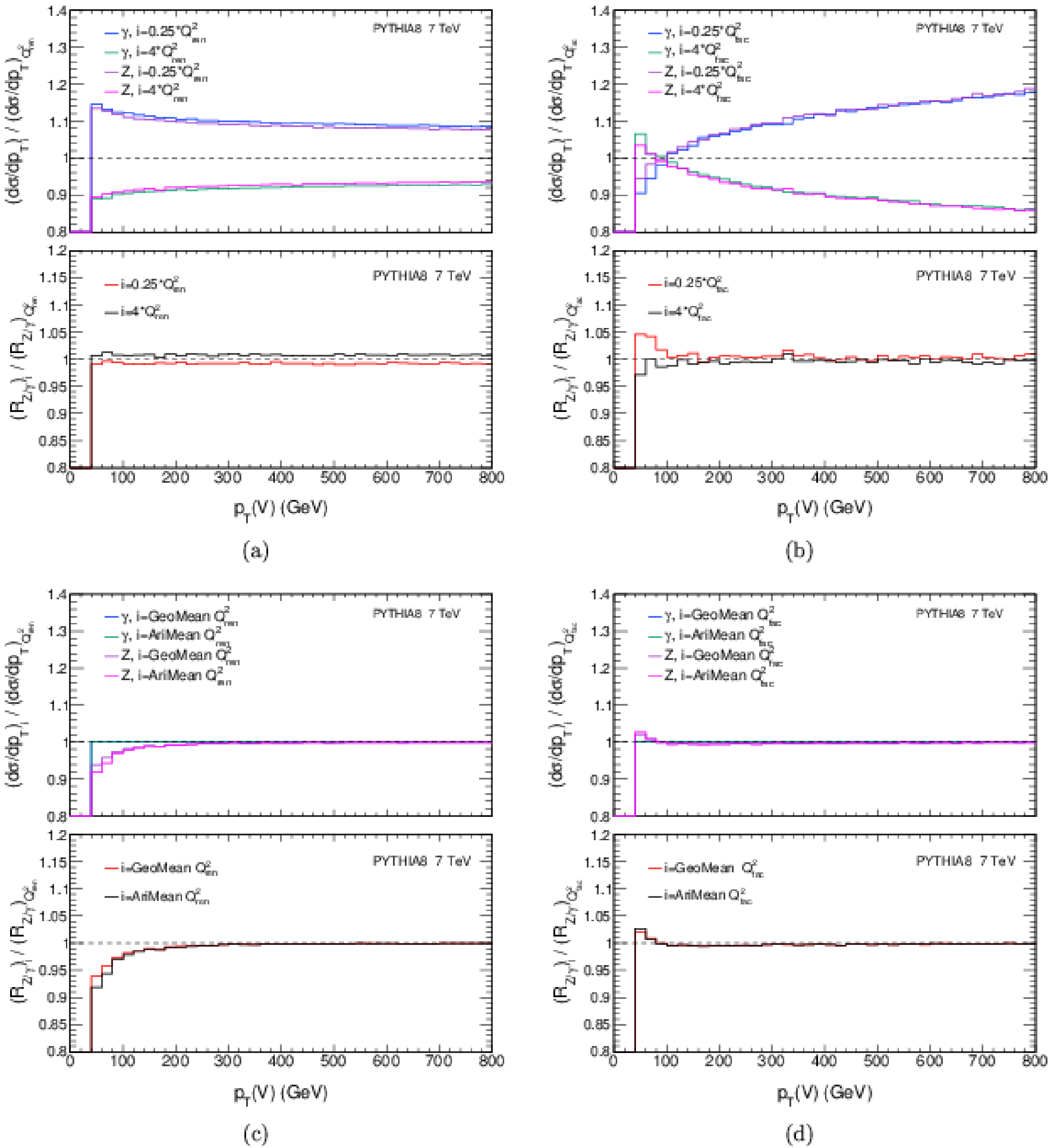
- photon isolation modelling: we take the difference between $\Delta R_{min} = 0.4$ (default) and 0.6 as indicative
  → ±5% on the ratio at high p_T

- electroweak HO corrections: not included, but see later


γ, i=GRV98
γ, i=CTEQ5L
Z, i=GRV98
Z, i=CTEQ5L
PYTHIA8 7 TeV
$(d\sigma/dp_T)_i$ / $(d\sigma/dp_T)_{MSTW08}$
i=GRV98
i=CTEQ5L
PYTHIA8 7 TeV
$(R_{Z/\gamma})_i$ / $(R_{Z/\gamma})_{MSTW08}$
$p_T(V)$ (GeV)


MSTW08 LO 68% cl errors
MSTW08 NLO
GRV98 LO
CTEQ5L
$Q^2 = 10^4$ GeV^2
$d(x,Q^2)/u(x,Q^2)$ relative to MSTW08 LO
x

μ_R variation μ_F variation



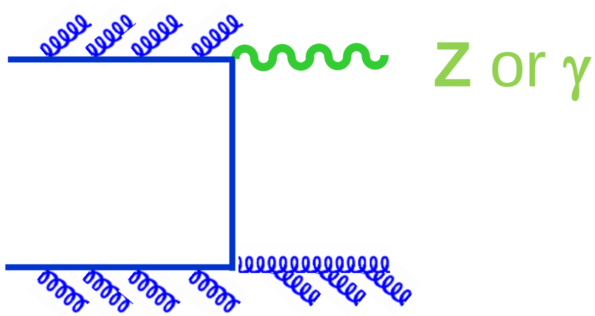
GeoMean / AriMean Q^2 are the geometric / arithmetic means of the transverse masses of the particles in the 2→2 hard process (PYTHIA)

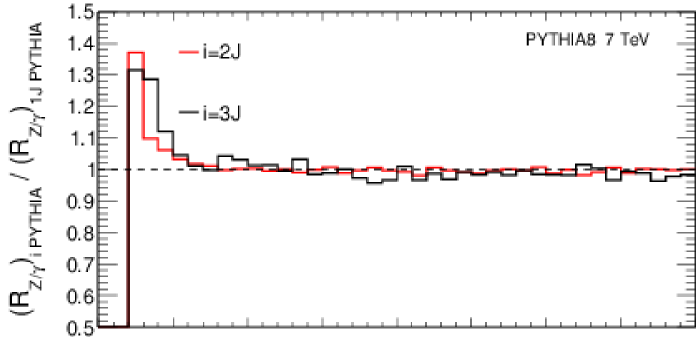
full event simulation (using PYTHIA8)

V8.150

- MC: 2 → 2 ($q\bar{q}\to Vg$, $qg\to Vq$) + PS + had$^{n.}$+ MPI
- photon treatment as ATLAS (e.g. arXiv:1108.0253):
  - isolation: E_T^{iso} < 4 GeV in $\Delta R<0.4$
  - but no $\pi^0\to\gamma\gamma$ etc. background in this study
- jet reconstruction (FastJet, anti-k_t, R=0.4)

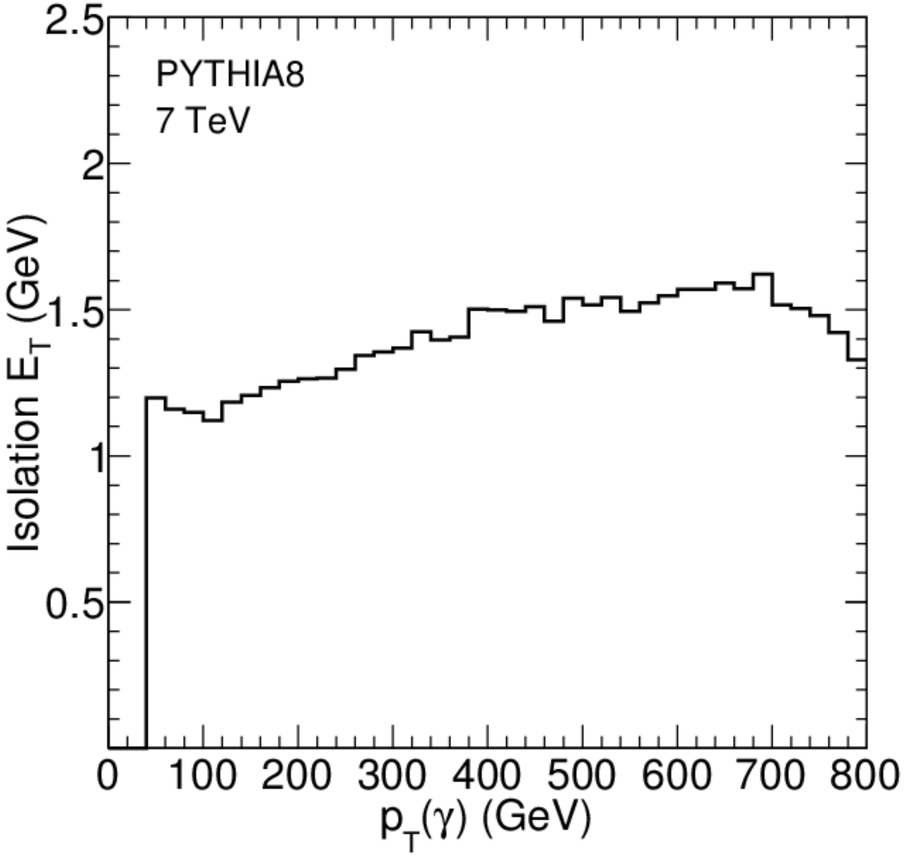
- first, compare ME (GAMBOS) with PYTHIA (parton-level)
  - $R(Z/\gamma, \text{1jet})^{ME} = R(Z/\gamma, \text{1jet})^{PYT}$ (same hard process)
  - $R(Z/\gamma, \text{2,3,..jet})^{ME} \neq R(Z/\gamma, \text{2,3,..jet})^{PYT}$ ('missing' 2→n hard processes in PYTHIA)
  - in fact, $R(Z/\gamma, \text{1jet})^{PYT} \sim R(Z/\gamma, \text{2,3,..jet})^{PYT}$ at high p_T

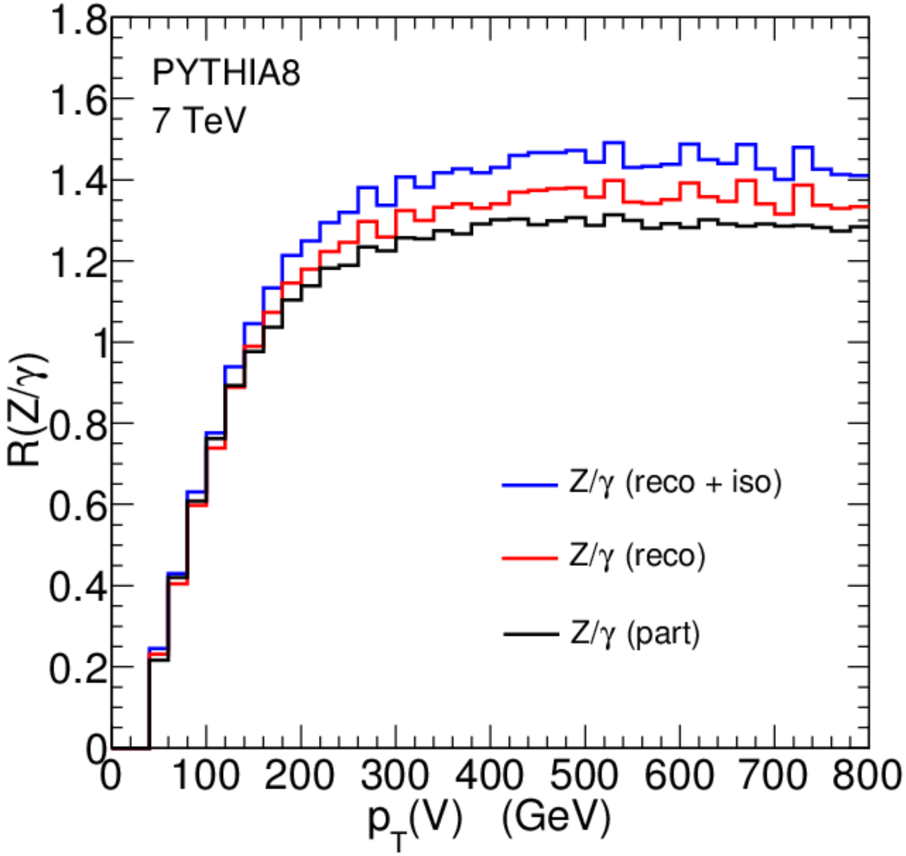




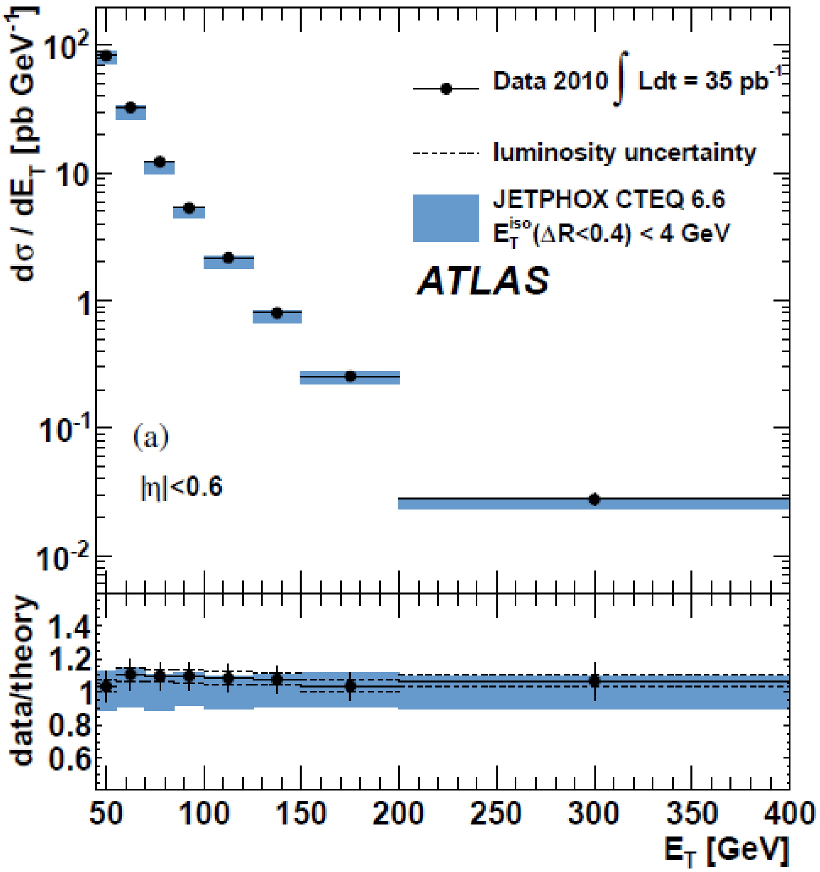
- second, study impact of hadronisation, reconstruction, isolation,... on R(Z/γ)

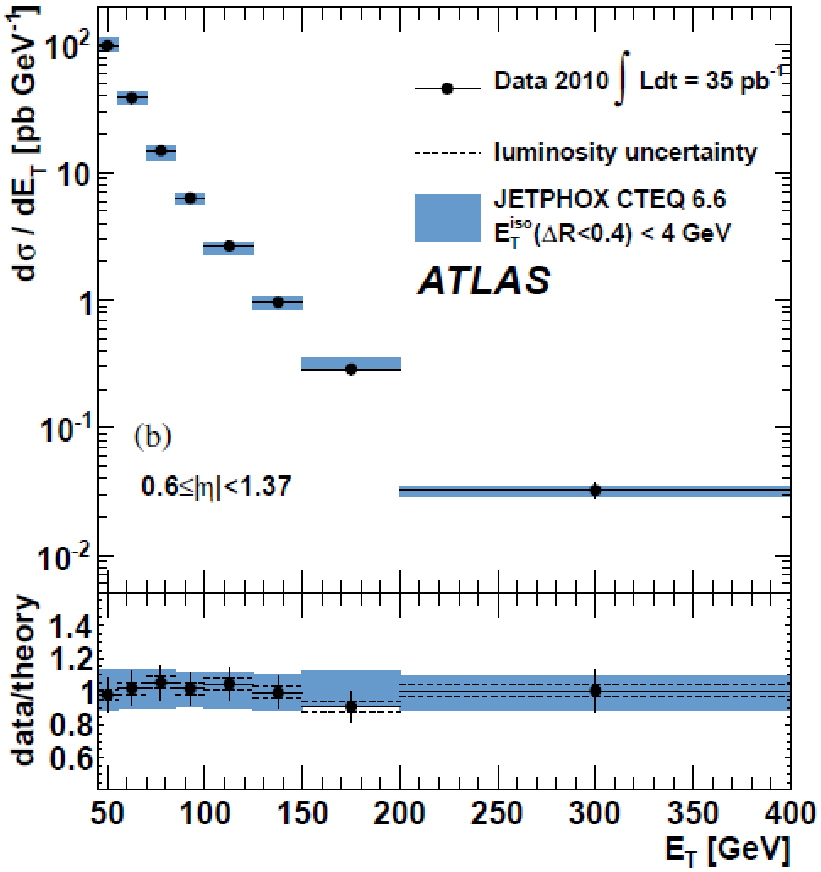
⇒ net effect is modest (~12%) increase in ratio at high p_T





ATLAS, arXiv:1108.0253





Note: systematic error ~ 5%-10%, decreasing slightly with E_T

background estimate for 0-lepton SUSY search

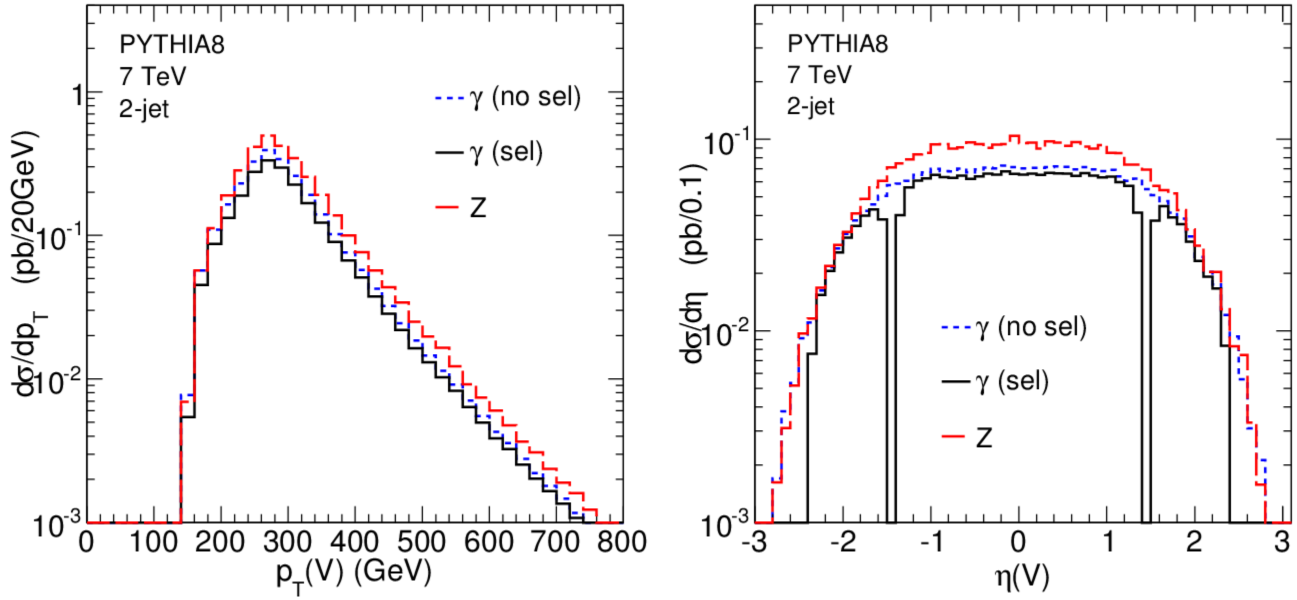
- generate and select photon events (as ATLAS)

$$p_T(\gamma) > 45 \text{ GeV}, \quad |\eta(\gamma)| < 2.37 \text{ excluding } 1.37 - 1.52, \quad E_T^{\text{iso}} < 4 \text{ GeV}$$

- apply SUSY event selection to these events, replacing p_T^γ by E_T^{miss} and selecting 2,3,.. jet samples

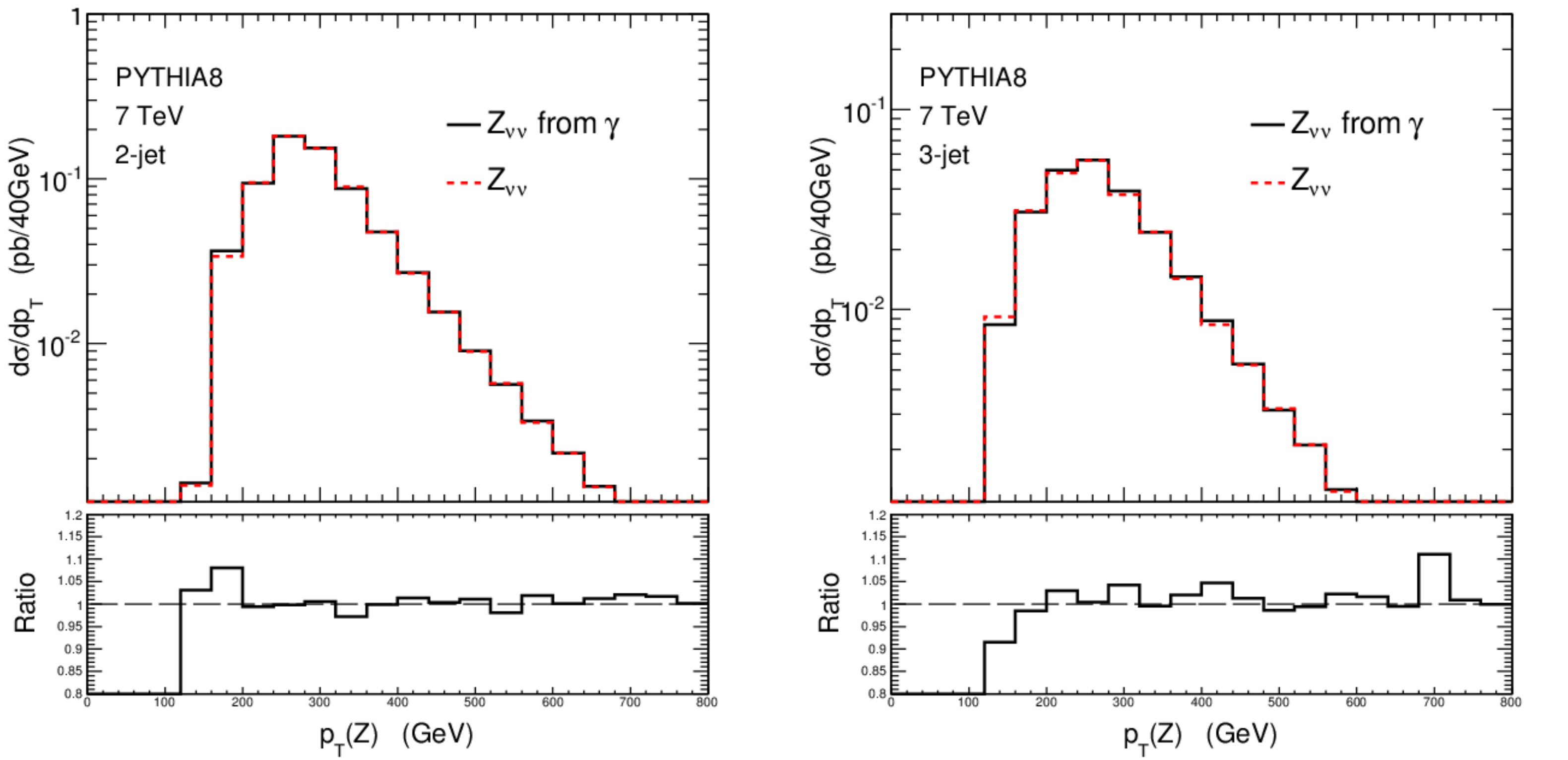
$$p_T(j_1) > 120 \text{ GeV},\ p_T(j_{>1}) > 40 \text{ GeV}, p_T(V) > 100 \text{ GeV}, \Delta\phi(V, j_i) > 0.4, \quad p_T(V)/M_{\text{eff}} > 0.3,\ M_{\text{eff}} > 500 \text{ GeV}$$

- correct for isolation efficiency and photon acceptance



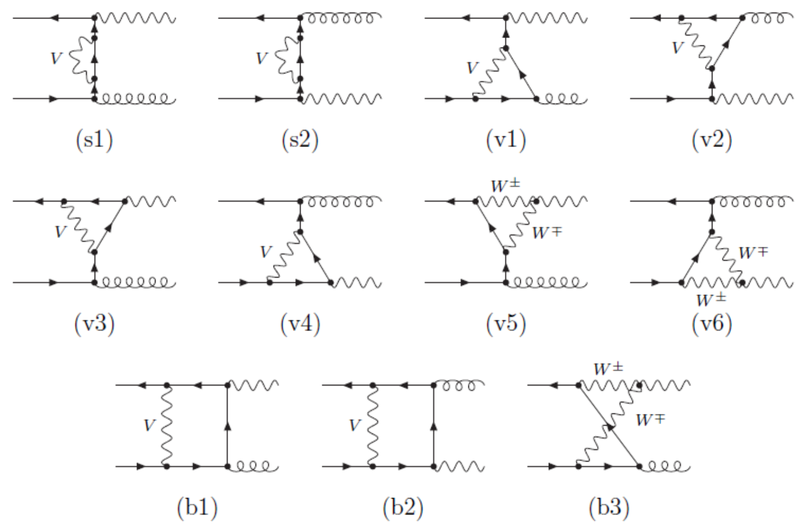
- then multiply by R(Z/γ) B(Z$\rightarrow\nu\nu$) to obtain estimate for missing transverse energy distribution

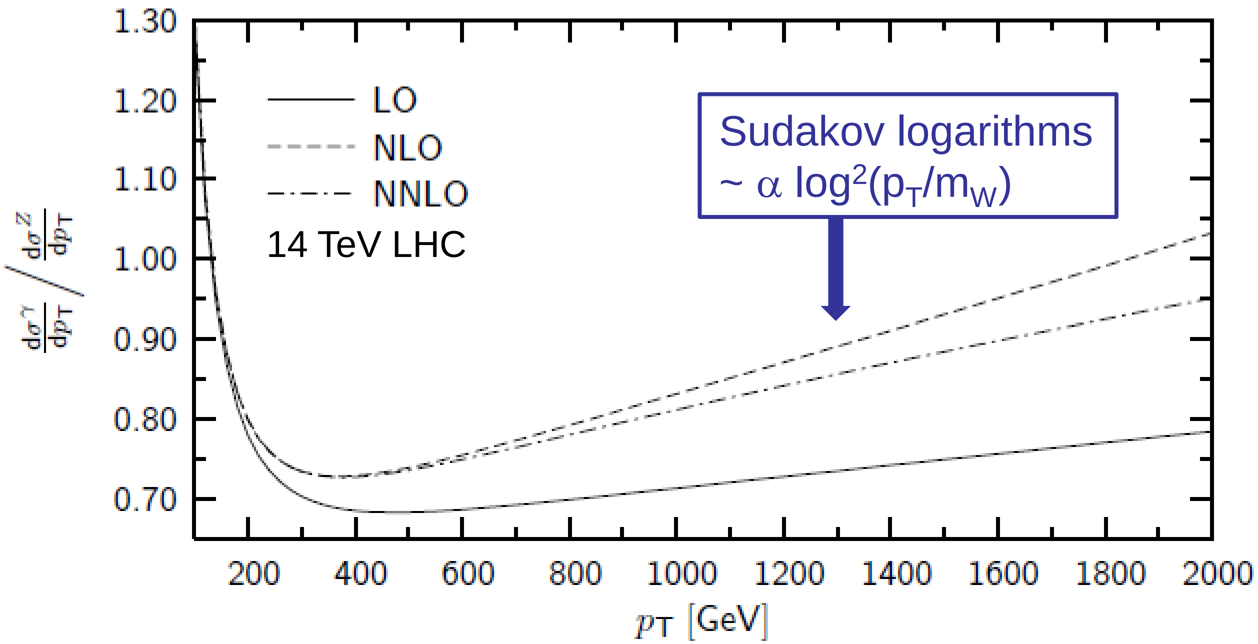
- cross-check: use R(Z/γ)$|_{\text{PYTHIA}}$ and check get E_T^{miss} distribution as generated directly with PYTHIA



HO weak corrections to R(Z/γ)

... have been considered by
J.H. Kuhn, A. Kulesza, S. Pozzorini, M. Schulze, JHEP 0603:059, 2006, arXiv:hep-ph/0508253





R(Z/γ) reduced by ~6% and ~11% for p_T=300 and 800 GeV, respectively

summary

- we have studied the method of using γ + jets to calibrate $Z(\rightarrow \nu\nu)$ + jets at high E_T^{miss}
- the method requires
  - an accurate theory calculation of the ratio of Z and γ p_T distributions at high p_T – we have studied a variety of sources of uncertainty, the net effect of which appears to be less than $\pm$10%
  - full event simulation to establish the impact on parton-level calculations – the main effect appears to be correcting for photon event selection, with estimated uncertainty at the $\pm$ few % level
- …further improvements:
  - full NLO pQCD for all relevant multijet final states
  - further consideration of electroweak corrections

extra slides