# Inclusive isolated prompt photon cross section paper status

L. Carminati

## What with photons in early data?

- Measurement of the single / double photon production cross sections (+ all the relevant distributions )
  - test of QCD predictions.
  - main backgrounds for many ‘discovery’ channels Higgs.

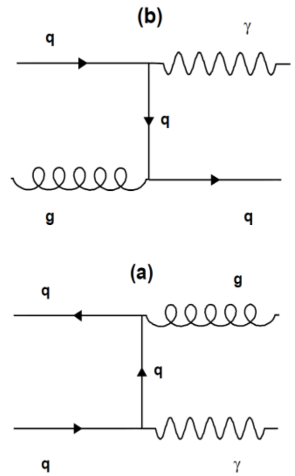
- Use direct photons as a input for PDFs: direct photons can be used to probe the gluon content of the proton. Check the predictions in eta distributions (for example) varying the PDFs sets. Hopefully direct photon data in the PDF fits again?

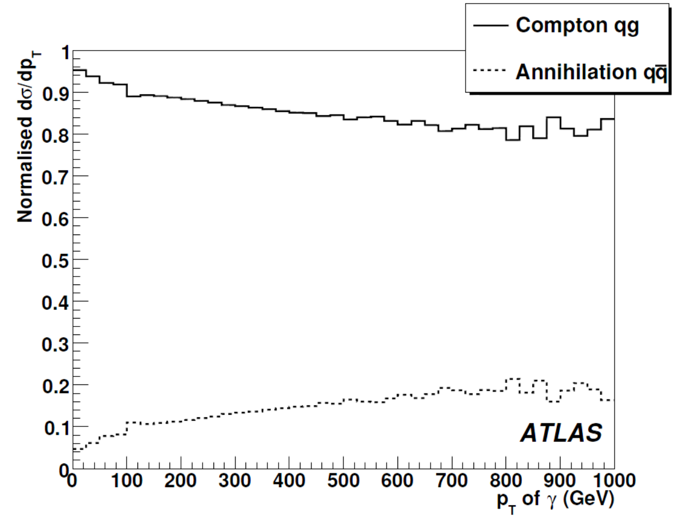
- A photon is a ‘nice’ object for jet/MET calibration purpose

- Can we say something at least on the presence of new physics?
  - Exclude higgs decays into two photons?
  - Observe or exclude gravitons decaying into a 2 photons pair? UED ?
  - Exclude decays of neutralinos?

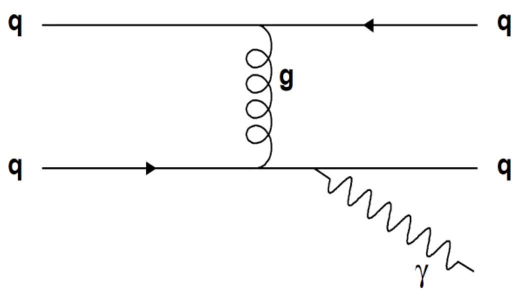
# The Direct contribution and the 'fragmentation' issue :

❑ Direct : at LO the contribution to direct prompt photon production is (relatively) easy. It is given by the processes in the plots : all these are order $O(\alpha\alpha_S)$ .
❑ Fragmentation (a photon behaves like an anomalous hadron coming from the collinear fragmentation of a coloured high $p_T$ parton) contribution is usually added (Pythia) using parton shower models



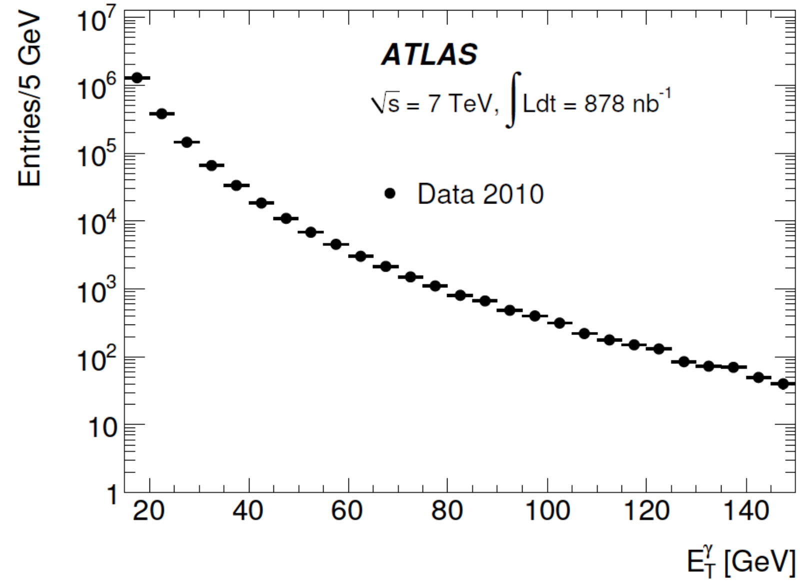

❑ Technically the fragmentation contribution emerges from the HO corrections to Born process: at NLO collinear singularities occur in the calculation of the contribution for example from the subprocess $qq \rightarrow qq\gamma$




These singularities are factorized and absorbed into q/g fragmentation functions into photons $D_{q\gamma}(M_F)$ and $D_{g\gamma}(M_F)$ : these functions can't be calculated and are determined experimentally (Aleph, hep-ex/9708020v1)

## More details :

A. Use almost all runs up to period E4 (except 158443 and 160975) : g10_loose was unprescaled in the whole period. ~ 880 $nb^{-1}$ (breakdown of the lumi in different OQ periods)




B. Eta and pt binning :
   A. Eta : [0.00, 0.60), [0.60, 1.37), [1.52,1.81), [1.81,2.37)
   B. $p_T$: [15,20), [20,25), [25,30), [30,35), [35,40), [40,50), [50,60), [60,100) GeV

C. Preselection :
   A. Event is in the standard egamma GoodRunList
   B. Event passes EF_g10_loose
   C. The primary vertex has at least 3 tracks
   D. The photon candidate passes the e/gamma object quality (OQ) cuts
   E. The photon candidate passes the new PhotonModifiedTight cuts
   F. The photon has a corrected EtCone40 less than 3 GeV

EtCone40_corrected : isolation energy in a 0.4 cone corrected for signal leakage and pileup/UE contribution (event by event basis)

$$\frac{d\sigma}{dp_T} = \frac{N \cdot P}{L_{\text{int}} \cdot \Delta p_T \cdot \varepsilon}$$

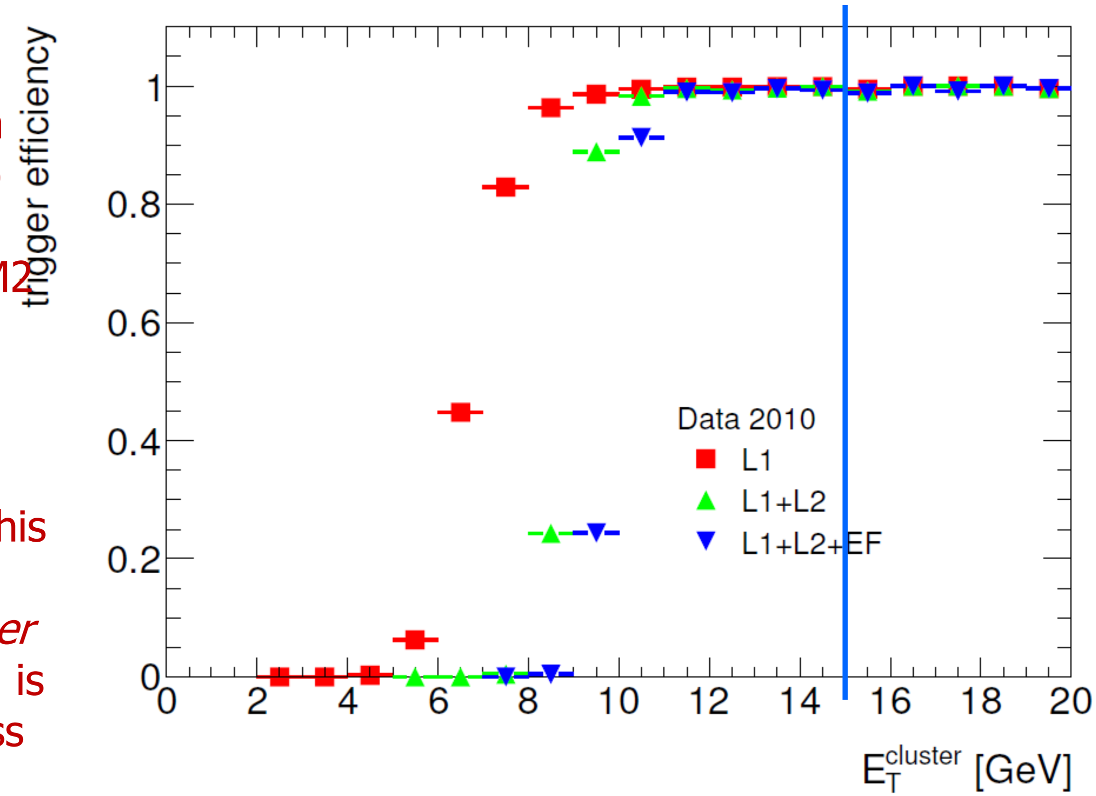
In the following I will briefly describe the most relevant issues for each of the ingredients

## Trigger efficiency

The efficiency is estimated in two steps:

- First, using a prescaled sample of minimum bias triggers, the efficiency of a lower (2 GeV) threshold L1 calorimeter trigger (L1 EM2) is determined. The measured efficiency of L1 EM2 is 100% for all photon candidates with reconstructed *ET above 15 GeV passing* tight identification criteria.

- Then, the efficiency of the trigger used in this analysis (the g10 loose, with nominal *ET threshold set to 10 GeV in the high-level trigger and at 5 GeV in the underlying level*-1 trigger) is measured using the sample of events that pass the L1 calorimeter trigger with a 2 threshold. The efficiencies with respect to the offline selection are computed for reconstructed photon candidates passing the tight identification criteria and with isolation energy below 3 GeV as a function of the transverse energy.




$\varepsilon$ = 99.5% ± 0.5%

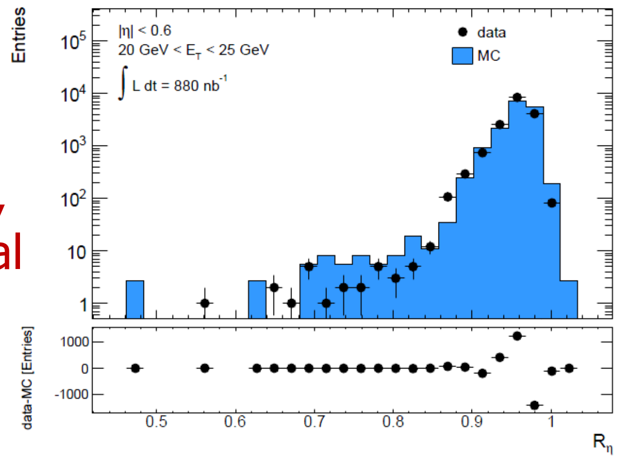
# Photon identification issues :

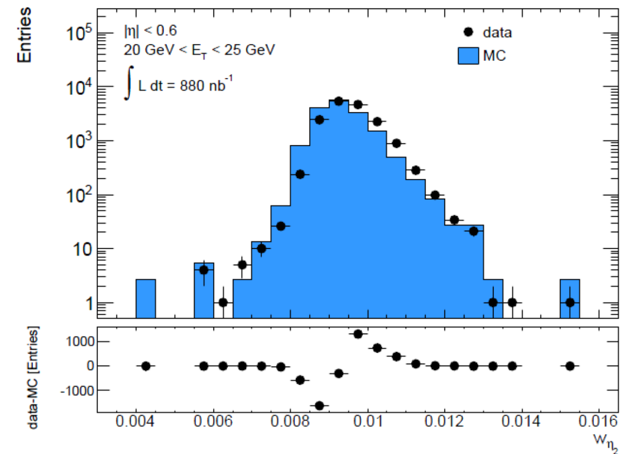
Ok, no clean source of photons to rely on but we can't trust blindly the MC.

A. Check the data/MC discrepancies on photon candidates : JFXX MC (dijets) vs Data
B. Infer photon ID information from W electrons

Facts about electrons and photons description in the MC:

A. The MC does not describe accurately the e/photons shapes. The most critical variables are Rη and Wη2, the second sampling lateral shower developments on which we are cutting very tightly



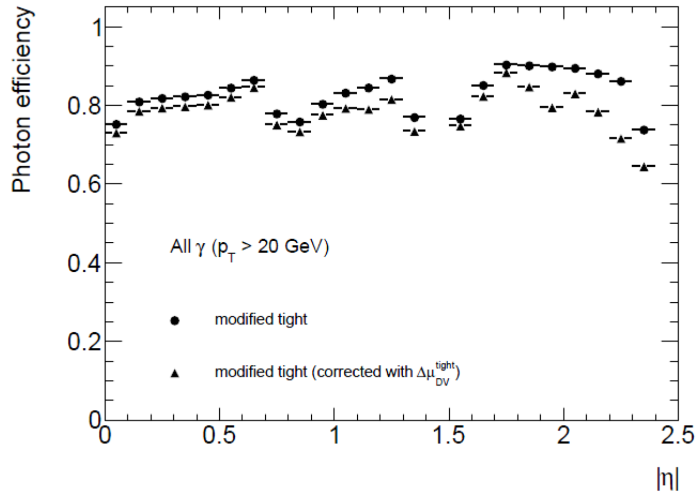



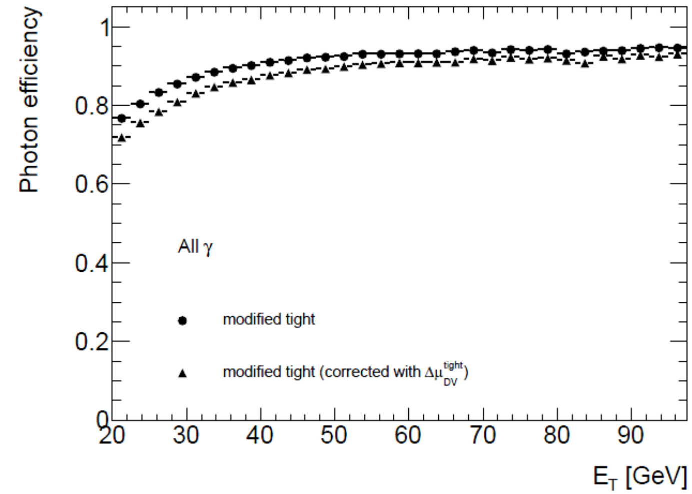

B. To reduce the impact of the inaccurate MC description a new photon tight robust menu has been studies relaxing only Rη and Wη2 by the same discrepancy observed between data and MC distribution at the loose level.
   A. Expected to reduce discrepancy between nominal and true efficiency :
   B. Acceptable price in purity loss (few%) with a slight increase in efficiency

# Is the robust menu safe enough ?

## Nominal MC efficiency for modified tight corrected from data driven inputs:

A. Extract the shapes of each discriminating variable from loose candidates
B. Assume the difference is a pure shift and extract a fudge factor for each variable
C. Take a pure signal MC sample and event by event move each DV value by the fudge factor and recompute isEM : correlations (at least the ones from MC) are taken into account




## Central value from the corrected MC (direct+brem) with TightRobust seems fair enough : how much fair ?

A. Check that the pure shift assumptions is fair enough : distorted vs nominal geometry
B. Discrepancies of predicted efficiencies from different selections. Correction factors from the shift of the means of the distributions : at the container, loose, tight-X, tight-(group of correlated variables), tight level

| | $\sigma_{\varepsilon\mathrm{ID}}^{\mathrm{MC\ correction}} = \sqrt{\Delta\varepsilon^2_{\mathrm{method}} + \Delta\varepsilon^2_{\mathrm{sample}}}$ | | | |
|---|---|---|---|---|
| | $\eta$ | | | |
| $E_T$ [GeV] | 0-0.6 | 0.6-1.37 | 1.37-1.81 | 1.81-2.37 |
| | all $\gamma$ | | | |
| [15 – 20) | 5.1 | 5.9 | 4.8 | 4.9 |
| [20 – 25) | 4.8 | 5.9 | 3.5 | 6.5 |
| [25 – 30) | 4.8 | 5.0 | 2.6 | 8.2 |
| [30 – 35) | 4.0 | 4.0 | 1.7 | 7.3 |
| [35 – 40) | 3.3 | 3.9 | 0.6 | 6.1 |
| [40 – 50) | 2.5 | 3.3 | 0.1 | 5.4 |
| [50 – 60) | 1.8 | 2.6 | 0.8 | 4.5 |
| [60 – 100) | 1.4 | 2.1 | 1.0 | 3.9 |

# Other systematics :

The effect of several experimental aspects potentially biasing the measurement has been checked:

Table 10: Photon ID systematics

| Source | | systematic [$\Delta\epsilon$ %] |
|---|---|---|
| LAr cell gain corruption | Barrel | 0.5 |
| | EndCap | 1 |
| Hard/Brem composition | | 1 |
| Hard/Brem Pythia/Herwig central value | | 1 |
| EM scale | | Negligible |
| Pile-up | Barrel | 0.4 |
| | EndCap | 1.2 |
| OTX | | 0.7 (?) |

Table 16: Photon ID. Distorted material systematics

| | systematic [$\Delta\epsilon$ %] | | | | | |
|---|---|---|---|---|---|---|
| | All | | Reco | | isEM | |
| $p_T$ GeV | Barrel | Endcap | Barrel | Endcap | Barrel | Endcap |
| $[15, 20)$ | $5.8_5$ | $7.5_7$ | $3.6_4$ | $4_6$ | $4.4_6$ | $6.3_7$ |
| $[20, 25)$ | $4.6_2$ | $6.8_2$ | $0.7_1$ | $1.8_2$ | $4.4_2$ | $6.4_2$ |
| $[25, 30)$ | $3.7_2$ | $5.6_3$ | $0.7_1$ | $1.5_3$ | $3.4_2$ | $5_3$ |
| $[30, 35)$ | $3_3$ | $4.8_4$ | $0.6_2$ | $1.1_4$ | $2.7_3$ | $4.5_4$ |
| $[35, 40)$ | $2.9_4$ | $4_6$ | $1.0_3$ | $1.2_5$ | $2.2_3$ | $3.5_5$ |
| $[40, 50)$ | $2.3_4$ | $4.1_6$ | $1.0_3$ | $1.3_5$ | $1.5_3$ | $3.4_5$ |
| $[50, 60)$ | $0.34_5$ | $4.1_9$ | $0.5_4$ | $2.4_8$ | $0.17_4$ | $2.2_7$ |
| $[60, 100)$ | $0.8_6$ | $3.3_9$ | $0.8_4$ | $2.8_8$ | $0.13_4$ | $0.9_6$ |

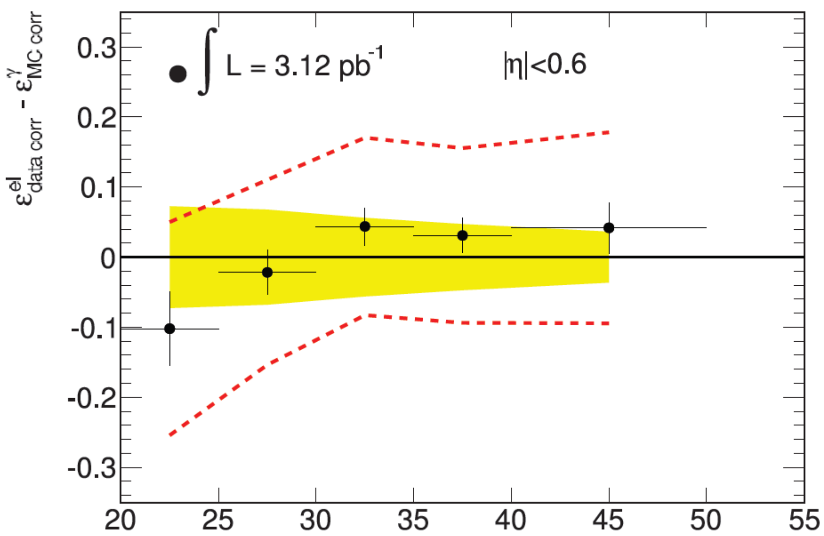
The dominant contribution comes from material effect : strongly pt and eta dependent

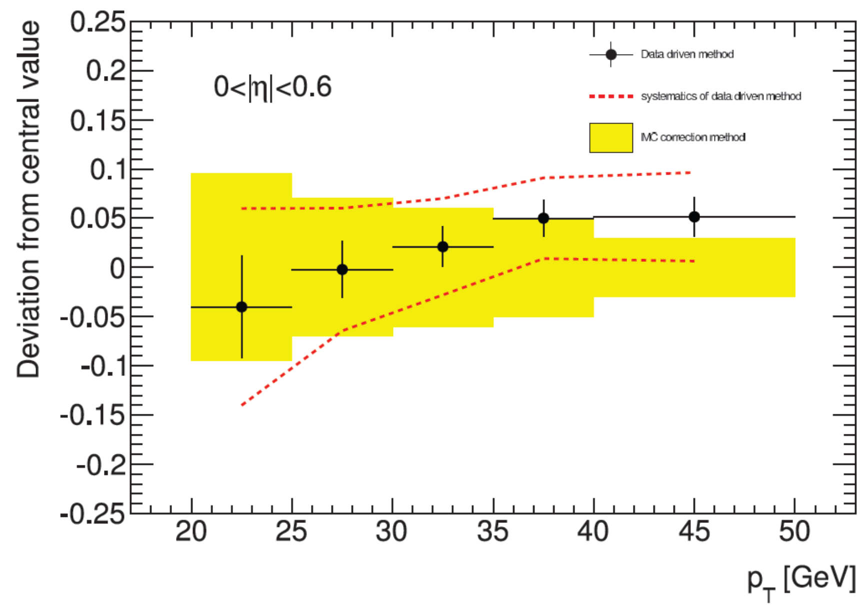
# Photon identification issues : infer efficiency from electrons ?

## Try to exploit the similarities between electrons and photons :

A. Select a pure unbiased sample of electrons from W
B. Reconstruct electrons as converted and unconverted photons
C. Measure the efficiency on data (with some level of uncertainty due to extrpolation)

| Electrons as unconverted photons | Electrons as converted photons |
|---|---|



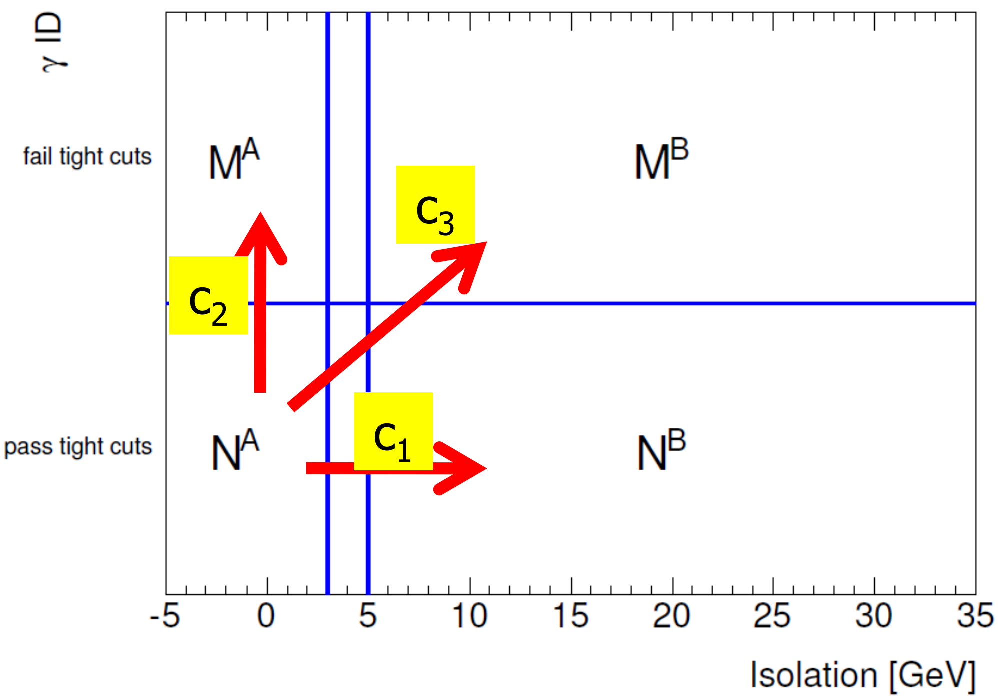

## Lessons from electrons:

- ❑ There are limitations (syst+stat) to extract photon ID information from electrons
- ❑ Even if with large uncertainties electron measurements give us confidence that we are not to far off with the central value of photon efficiency

## Photon purity estimation :

Two different methods are used to estimate the photon purity on the data:

A. 2D sidebands counting method : used in the conf5 conference note. Tight-4 strips variable on one axis and corrected isolation on the other. Corrections for signal leakage and background correlation (?)




$$N^A_{\mathrm{sig}} = N^A - \left[ (N^B - c_1 N^A_{\mathrm{sig}}) \frac{M^A - c_2 N^A_{\mathrm{sig}}}{M^B - c_3 N^A_{\mathrm{sig}}} \right] \overbrace{\left( \frac{N^A_{\mathrm{bkg}}}{N^B_{\mathrm{bkg}}} \frac{M^B_{\mathrm{bkg}}}{M^A_{\mathrm{bkg}}} \right)}^{R_{mc}}$$

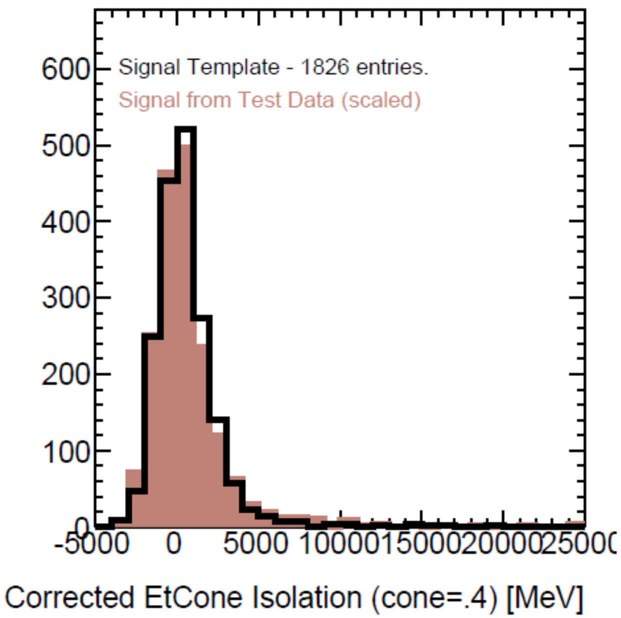
A. $c_X$ : signal leakage in the background control regions (~5%)
B. $R_{mc}$ : background pseudo-correlation factor (ideally ~1)

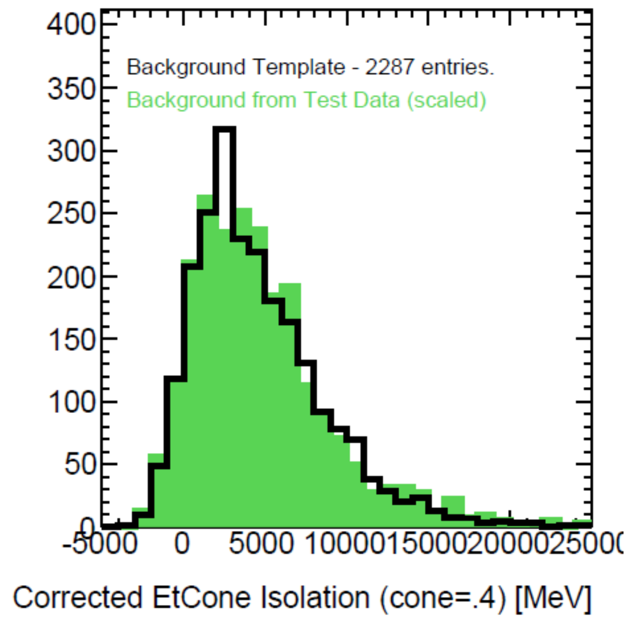
Systematics checks : change the isolation control region definition, bit reversal, signal leakage, $R_{mc}$, energy scale

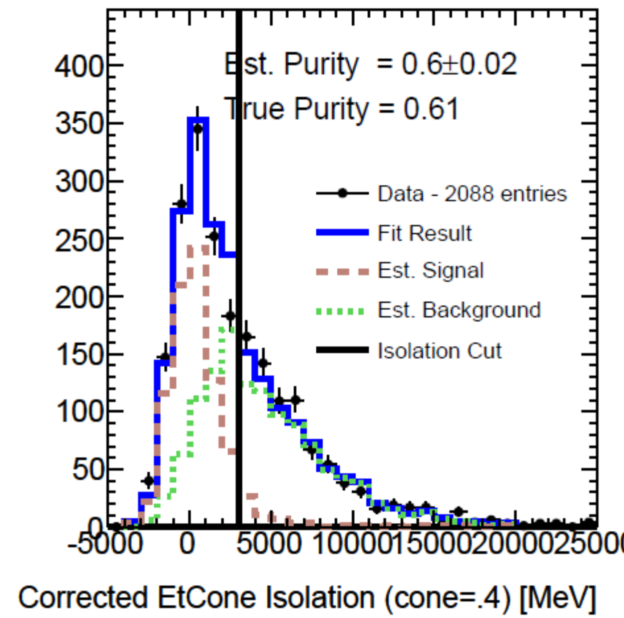
## Photon purity estimation :

### B. Full isolation template fit :

A. Signal template, from truth or "enhanced signal" sample Electrons from W/Z, eventually from Z $\rightarrow ll\gamma$, etc
B. Background template, from "enhanced background". Usually from reversing photon ID cuts
C. Fit the data to a sum of signal+background In this case, RooFit (likelihood)
D. Isolation cut applied after the fit; purity then estimated for signal region

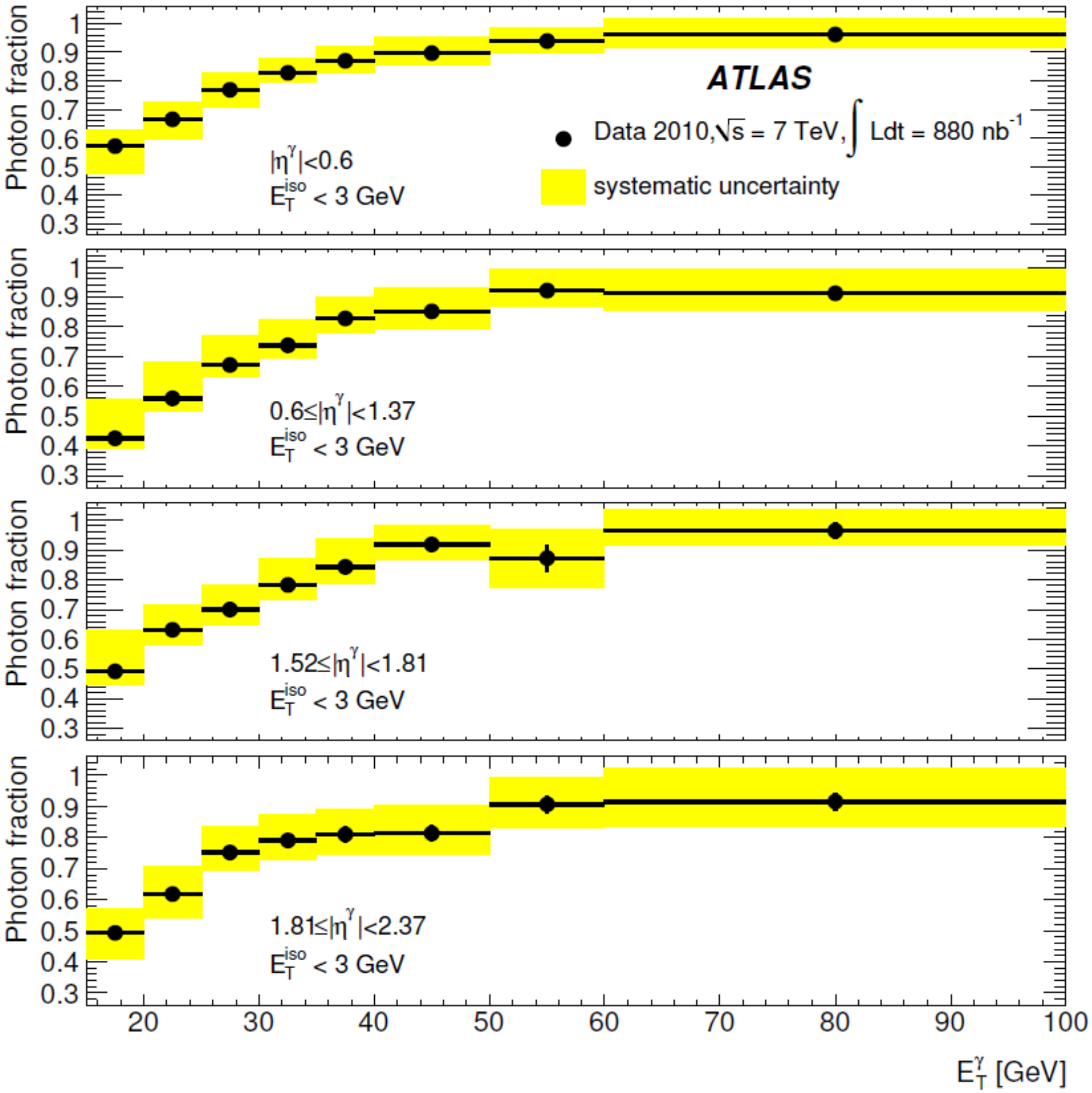



Several systematics check : isolation templates for Direct/Brem/electrons, checks on bit reversal for background, fitter etc.

# Photon purity estimation :




- The results from 2D sidebands method and full isolation template fit agree within 5%
- Systematics going from 10% to 5% at high pt. Similar in both methods

# Unfolding :

The problem : we are interested in the measurement of the average differential cross section for the production of isolated prompt photons in a certain bin i of (true) $E_T$ (integrated over one true $\eta$ bin k)

$$\left\langle \frac{d\sigma_i^{\mathrm{isol},k}}{dE_T^{\mathrm{true}}} \right\rangle = \frac{1}{\int \mathcal{L}dt} \frac{N_i^{\gamma,\mathrm{true,isol},k}}{\Delta E_{T,i}^{\mathrm{true}}}$$

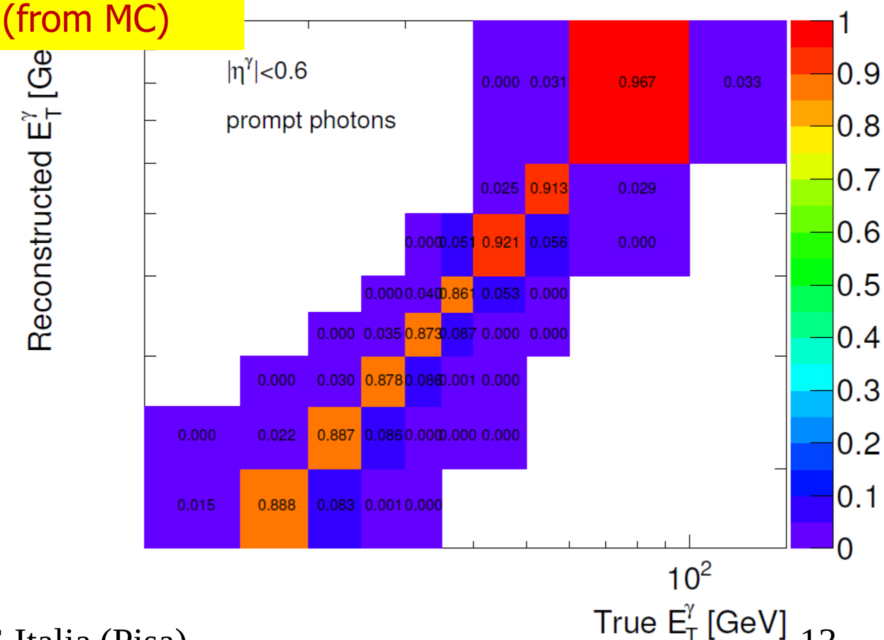
measurement

$$N_i^{\gamma,\mathrm{reco,isol},k} = \left( \int \mathcal{L}dt \right) \varepsilon^{\mathrm{trig}}\, \varepsilon_i^{\mathrm{offl},k} \sum_j R_{ij}^k\, \varepsilon_j^{\mathrm{reco},k}\, \Delta E_{T,j}^{\mathrm{true}} \left\langle \frac{d\sigma_j^{\mathrm{isol},k}}{dE_T^{\mathrm{true}}} \right\rangle$$

truth

Response matrix (from MC)

The elements of $R^k_{i\,j}$ represent the probability for a prompt photon of true transverse energy in bin j, reconstructed in the k-th $|\eta|$ bin and having experimental isolation lower than 3 GeV, to have reconstructed transverse energy in bin i.




## ❑In general not a simple matrix inversion:

- ❑ Bin by bin unfolding This method works well if the bin-to-bin migrations are small, and transverse energy smearing is smaller than the bin size
- ❑ Bin by bin unfolding agrees within 2% with the full glory procedure
- ❑ Systematic due to energy scale uncertainty (3%) estimated at the unfolding level

# Theoretical cross section

## Inclusive isolated photon cross section computed using JetPhox (NLO) :

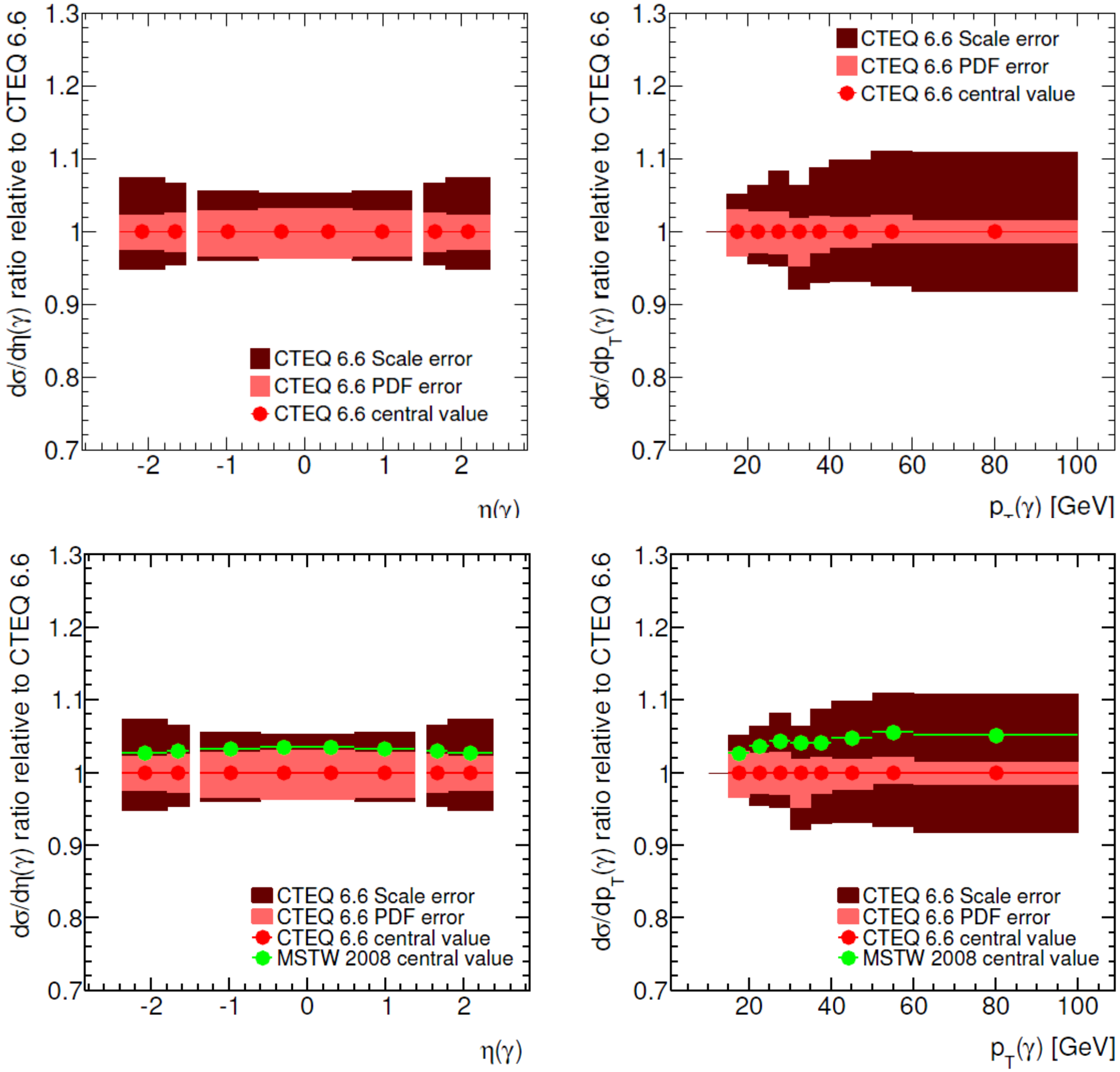
A. Computes NLO cross section with fragmentation contribution

B. Isolation cut tuned at 5 GeV in a cone of 0.4 : estimated from Pythia parton level isolation

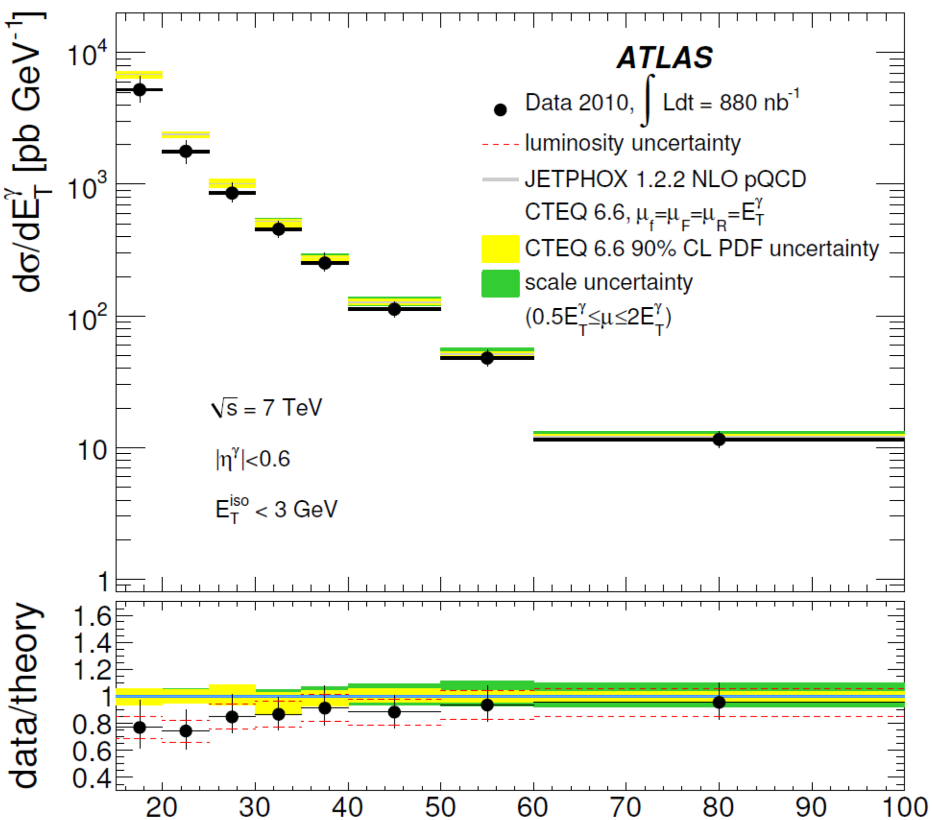
C. Errors varying the scales and the PDFs eigenvectors

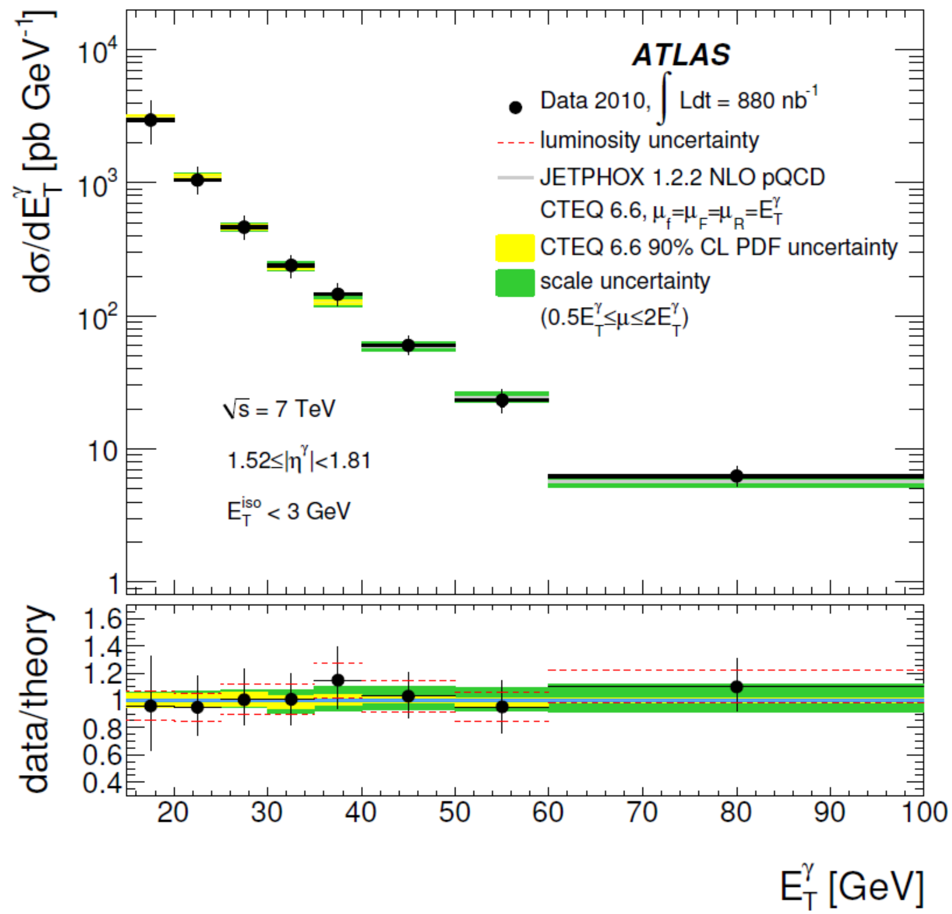
D. Errors for different PDFs very similar and going from 5 to 10%

E. Central value from different PDF sets within the errors



# Data-Theory comparison



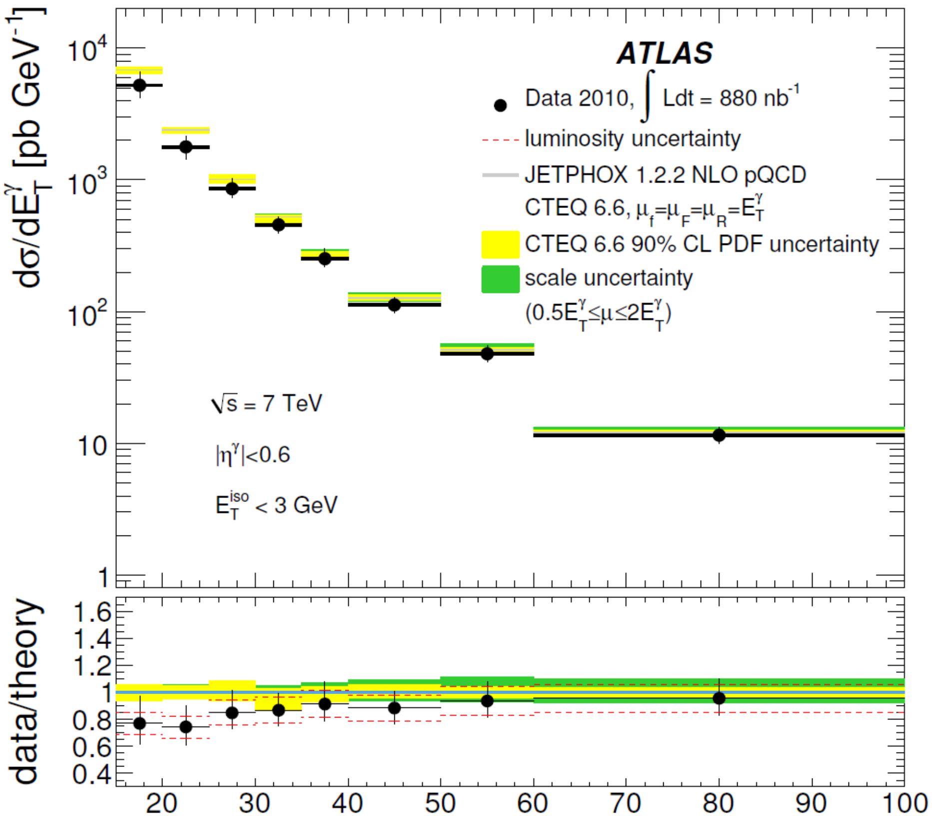



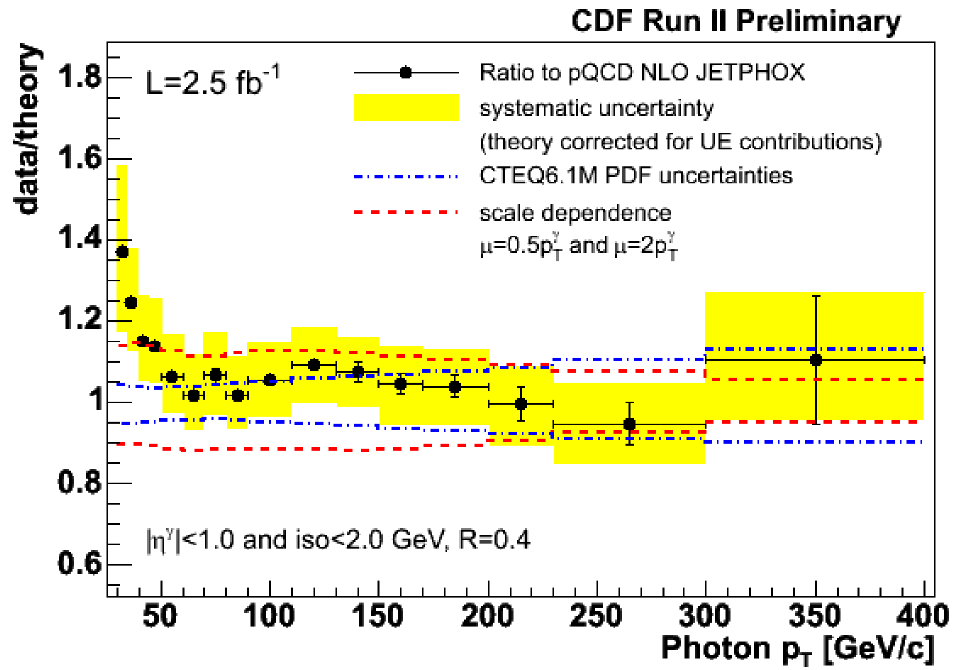
# Experimental cross section systematics

## Systematics for the 2D sidebands method in the eta<0.6 bin

| $E_T$ min [GeV] | $E_T$ max [GeV] | $\sigma$ [nb/GeV] | stat [nb/GeV] | syst (purity) [nb/GeV] | syst (efficiency) [nb/GeV] | syst (escale) [nb/GeV] | syst (lumi) [nb/GeV] | tot [nb/GeV] |
|---|---|---|---|---|---|---|---|---|
| 15.0 | 20.0 | 5.2576 | $\pm 0.1116$ | $^{+0.5186}_{-0.5186}$ | $^{+1.1264}_{-0.7569}$ | $^{+0.6335}_{-0.5118}$ | $\pm 0.5789$ | $^{+1.3970}_{-1.0565}$ |
| 20.0 | 25.0 | 1.7803 | $\pm 0.0445$ | $^{+0.1662}_{-0.1662}$ | $^{+0.2959}_{-0.1712}$ | $^{+0.1758}_{-0.2214}$ | $\pm 0.1960$ | $^{+0.3848}_{-0.3285}$ |
| 25.0 | 30.0 | 0.8574 | $\pm 0.0243$ | $^{+0.0672}_{-0.0672}$ | $^{+0.1257}_{-0.0660}$ | $^{+0.0798}_{-0.0766}$ | $\pm 0.0944$ | $^{+0.1651}_{-0.1238}$ |
| 30.0 | 35.0 | 0.4558 | $\pm 0.0156$ | $^{+0.0275}_{-0.0275}$ | $^{+0.0383}_{-0.0273}$ | $^{+0.0446}_{-0.0456}$ | $\pm 0.0502$ | $^{+0.0667}_{-0.0618}$ |
| 35.0 | 40.0 | 0.2530 | $\pm 0.0108$ | $^{+0.0152}_{-0.0152}$ | $^{+0.0201}_{-0.0137}$ | $^{+0.0372}_{-0.0266}$ | $\pm 0.0279$ | $^{+0.0462}_{-0.0352}$ |
| 40.0 | 50.0 | 0.1124 | $\pm 0.0048$ | $^{+0.0072}_{-0.0072}$ | $^{+0.0079}_{-0.0047}$ | $^{+0.0102}_{-0.0112}$ | $\pm 0.0124$ | $^{+0.0155}_{-0.0150}$ |
| 50.0 | 60.0 | 0.0482 | $\pm 0.0029$ | $^{+0.0025}_{-0.0025}$ | $^{+0.0032}_{-0.0018}$ | $^{+0.0051}_{-0.0049}$ | $\pm 0.0053$ | $^{+0.0072}_{-0.0065}$ |
| 60.0 | 100.0 | 0.0116 | $\pm 0.0007$ | $^{+0.0007}_{-0.0007}$ | $^{+0.0007}_{-0.0003}$ | $^{+0.0013}_{-0.0012}$ | $\pm 0.0013$ | $^{+0.0018}_{-0.0016}$ |

# For fun : data/theory comparison in ATLAS and CDF



## Conclusion :

A. First measurement of the inclusive isolated photon cross section in pp collisions with the ATLAS detector is ready. Quite difficult measurement, the best we can do with the available data and the present understanding of the detector (probably more advanced then CMS). Substantial contribution of the Milano group in the development of this analysis.

B. Supporting documentation
   A. ATL-COM-PHYS-2010-802 Title: First measurement of the inclusive isolated prompt photon cross section in $pp$ collisions at $sqrt{s}= 7TeV$ with the ATLAS detector
   B. ATL-COM-PHYS-2010-803 Title: Photon Identification for the Measurement of the Inclusive Isolated Photon Cross Section
   C. ATL-COM-PHYS-2010-804 Title: Purity Estimates for the Inclusive Isolated Photons Author(s): tbd, t
   D. ATL-COM-PHYS-2010-805 Title: Theoretical Predictions for Measurements of the Inclusive Isolated Photon Cross Section in $pp$ Collisions at $\sqrt{s}= 7\TeV$

C. The analysis has been approved at the SM plenary yesterday afternoon

D. Approval process continuing with the editorial board to come out with a paper.

## Inclusive isolated photon paper goals

- The isolated photon cross section measurement is rather difficult to extract and measure accurately : no clean sample of photons so in some points we have to rely on the MC extrapolation and be sure that we are properly taking into account systematic effects. This to stress a couple of caveats :

  A. It's not intended a precision measurement : systematic uncertainties ~25% to 10% depending on pt (no lumi).

  B. In some places we will put some conservative estimation of the systematics

  So what ?

  Prove that we are able to measure a difficult signal understanding the main sources of systematics associated to the measurement even with a small lumi

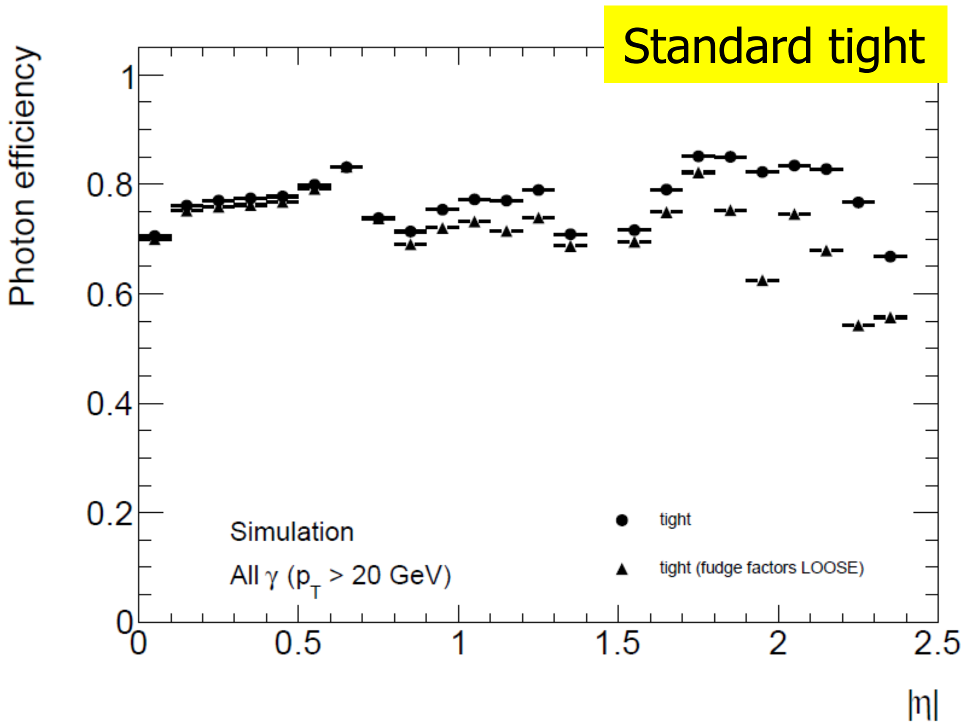
- Diphoton analysis required more integrated luminosity : 2010 data (30-50 $pb^{-1}$) enough for a good analysis (evidence and hopefully cross section)

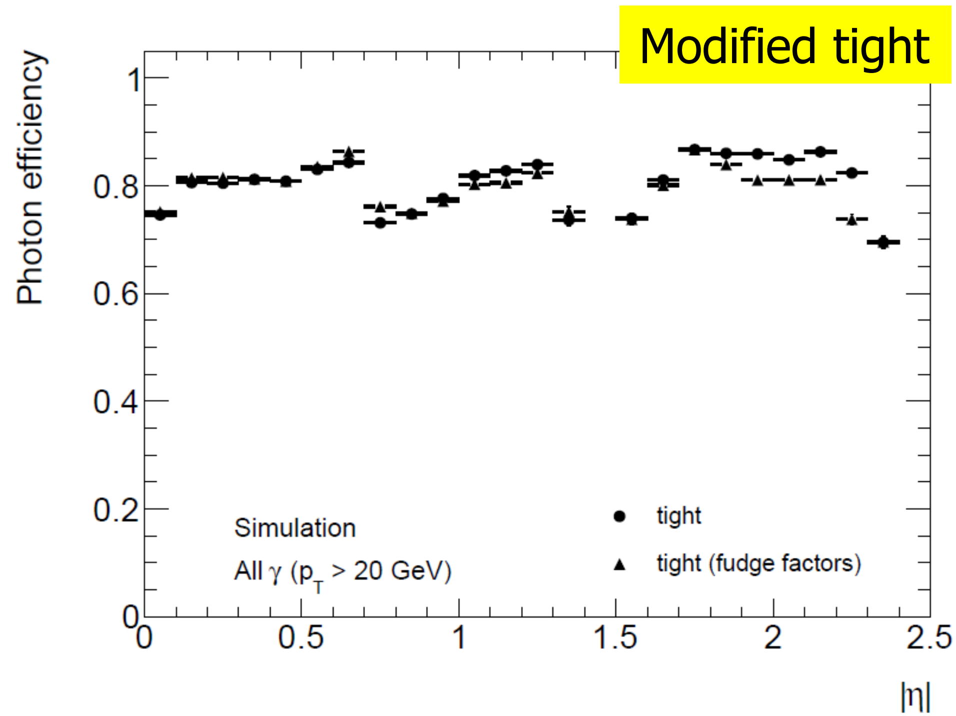
Historically an analysis with substantial presence of the Milano group

# Photon identification issues : fudge factor approach

Check data/MC agreement shifting discriminating variables :

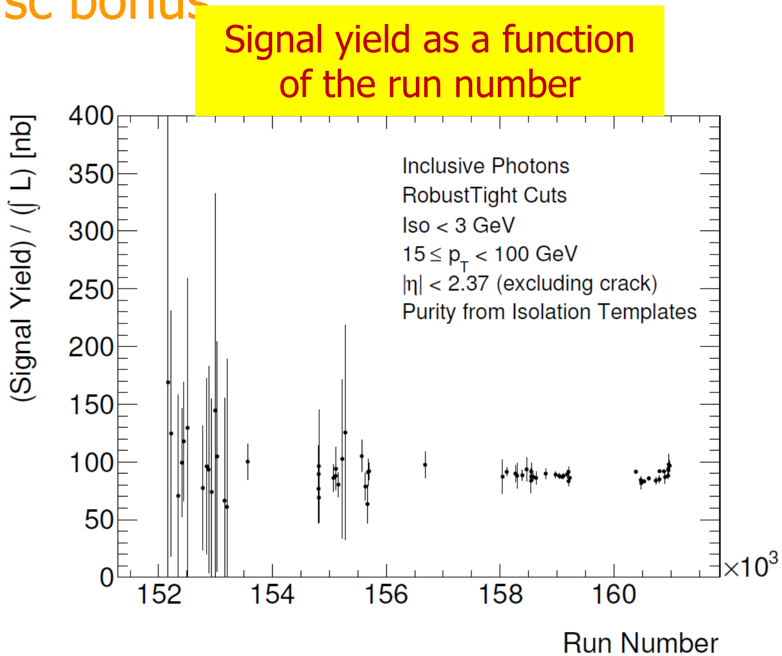
A. Extract the shapes of each discriminating variable from loose candidates
B. Assume the difference is a pure shift and extract a fudge factor for each variable
C. Take a pure signal MC sample and event by event move each DV value by the fudge factor and recompute isEM : correlations (at least the ones from MC) are taken into account



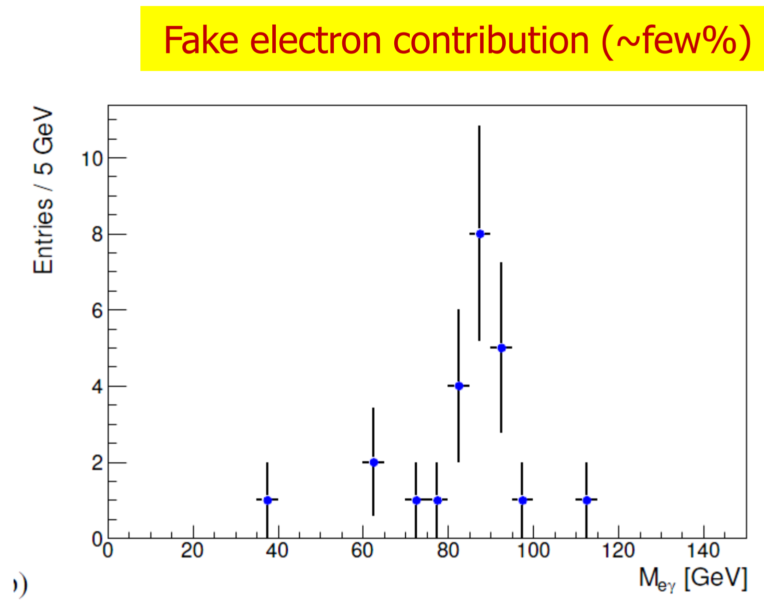




Few % disagreement remaining (5% max in the endcap) : probably good enough at this stage

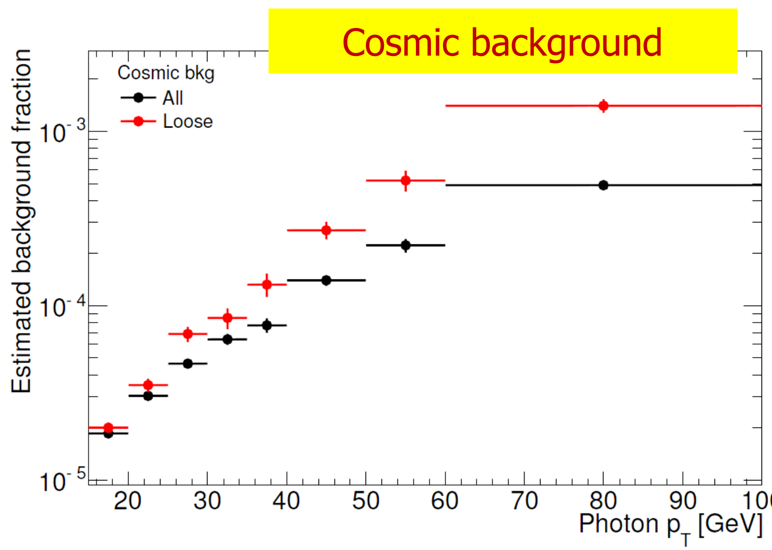
# Misc bonus:



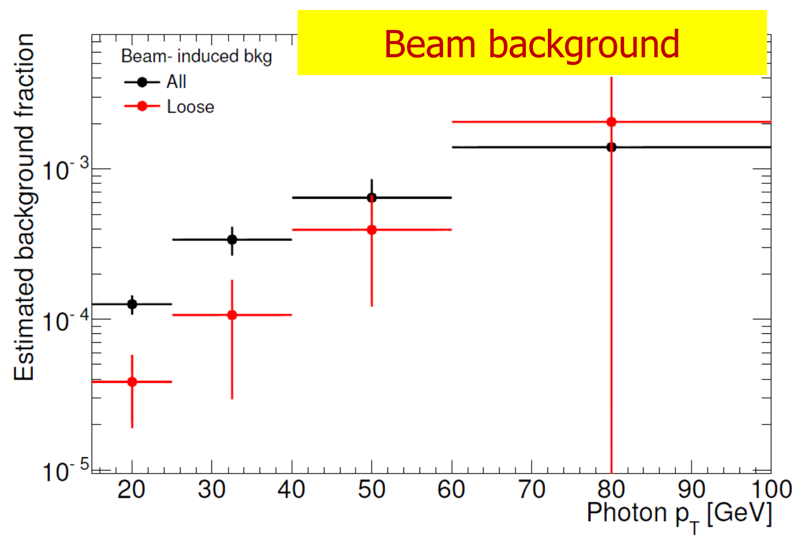
Signal yield as a function of the run number
(Signal Yield) / (∫ L) [nb]
Inclusive Photons
RobustTight Cuts
Iso < 3 GeV
15 ≤ p_T < 100 GeV
|η| < 2.37 (excluding crack)
Purity from Isolation Templates
×10^3
Run Number

Fake electron contribution (~few%)
Entries / 5 GeV
M_eγ [GeV]

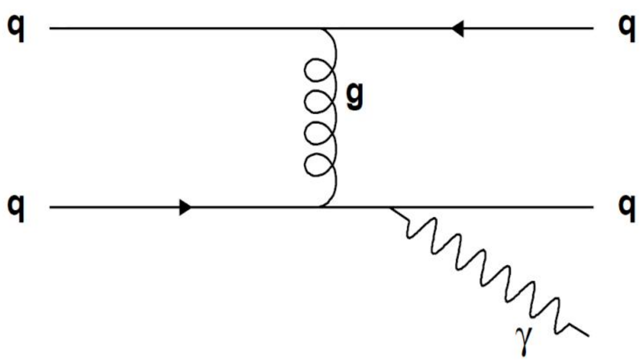



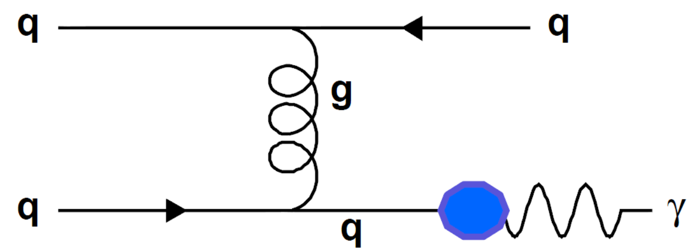
Cosmic background
Cosmic bkg
All
Loose
Estimated background fraction
Photon p_T [GeV]

Beam background
Beam- induced bkg
All
Loose
Estimated background fraction
Photon p_T [GeV]

# The ‘fragmentation’ within a full NLO calculation




$$d\sigma(AB \to \gamma X) = \sum_{a,b,c,d} \int dx_a \int dx_b F_{a/A}(x_a, M) F_{b/B}(x_b, M) \times \left[ d\sigma^{dir} + d\sigma^{frag} \right]$$

$$d\sigma^{dir} = d\sigma^{ab\to cd}(x_a, x_b, \mu, M, M_F)$$

$$d\sigma^{frag} = \int \frac{dz}{z} D_{c/\gamma}(z, M_F) d\sigma^{ab\to cd}(x_a, x_b, \mu, M, M_F)$$

- ❑ F(x,M) are the parton distribution functions in the (anti) proton
- ❑ D(z,$M_F$) fragmentation function into a photon ($z = P_T(\gamma)/P_T(c)$)
- ❑ σ hard scattering cross section (short distance)
- ❑ μ,M,$M_F$ renormalization/factorization (unphysical) scales

At NLO the definition of Direct vs Fragmentation becomes somehow arbitrary and depends on the unphysical parameter $M_F$ which discriminates between the 2 regimes