Preparatory study for QED ME/PS matching

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Study presentation
Global overview

1. Nowdays, generation of physical process are usually made using:
   - ME generation of the "hard event" with ME generator (ALPGEN(1), MadGraph(3) ...)
   - PS fragmentation and hadronisation made with PS algorithm (PYTHIA(2), Herwig ...)
2. The double counting problem between ME & PS **jets** has been adressed with "QCD matching" at the "particle level" (after the creation of partonic shower).
3. A similar double-counting problem exists for **photons** and has not yet been addressed by a matching algorithm.

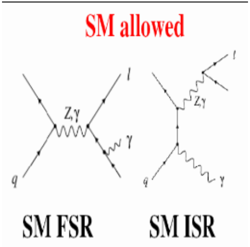
Goal:

Select the photons of ME or PS generators in the kinematic phase space where they are the most releavent avoiding double counting.

Our first test channel: $Z \to \mu\mu + \gamma$, its relevance for the LHC:

Use of "*internal bremstrahhlung*" allows the following measurements from (future) real data:

- photon trigger efficiency
- photon energy scale
- photon identification efficiency
- photon energy corrections
- E_t : $5 - 200\ GeV$ pertinent range for ECAL energy calibration (between typical Pt of π_0 and γ from Higgs Boson decay).



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More details of our study

We study the generation of this channel via two different procedures:

- First, use the ALPGEN generator in the inclusive channel $Z \rightarrow \mu\mu$, and then use the PYTHIA generator for the partonic shower. This sample will be called *Z0* because it comes from *Z* decay but **without** explicit γ in the hard event.

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- Second, we use ALPGEN to generate process $Z \to \mu\mu + \gamma$ before using PYTHIA (with ISR/FSR switched off in PYTHIA). This sample will be called *Z1* because ALPGEN generator forced a ME γ.

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So, in these two procedures, we use both PYTHIA and ALPGEN but forcing (or not) the creation of a ME γ. The underlying event and the hadronisation are supressed in order to allow the deconvoluted study of ME and PS γ

Goal of this study

- Identify phase space of possible observables where ME/PS descriptions differ: $\Delta_R(\gamma, \mu)$ and γ_{PT}
- Determinate zone of agreement between PS/ME description for defining a zone where we can choose "cutoffs" using a reference sample with very loose cuts.
- Check the robustness of this range under the "anti-double-counting veto" (to be described later)

  by studying the stability of:

  → the total cross-section: $\sigma_f = \sigma_i \times \frac{N_{final\_after\_veto}}{N_{generated}}$

  → the shape of the combined curves (Z0 + Z1) after veto application, in order to check if they are sensitive to the "cutoffs".
- If all is stable, select the "cutoffs" – at the generator level – as high as possible to increase generation efficiency.

Study presentation

Generator parameters for reference samples

"Reference" samples

Generated for both processes (Z0 & Z1) with the following loose cuts:

$PT_\mu > 15GeV$		$PT_\gamma > 1GeV$	(for Z1 only)
$\mid \eta \mid < 3.0$		$\mid \eta_\gamma \mid < 3.0$	(for Z1 only)
$M_{\mu\mu}$ $20GeV < M_{\mu\mu} < 150GeV$		$\Delta_R(\mu\gamma) > 0.05$	(for Z1 only)

We have used the following parameters

- PS has been made with `PYTHIA 6.408`
- In each event after PS we only plot the highest-pt γ with $\Delta_R > 0.05$ & $PT_{\gamma\gamma} > 1GeV$ & $|\eta| < 3.0$
- Both samples are normalized to one.

Generation parameters

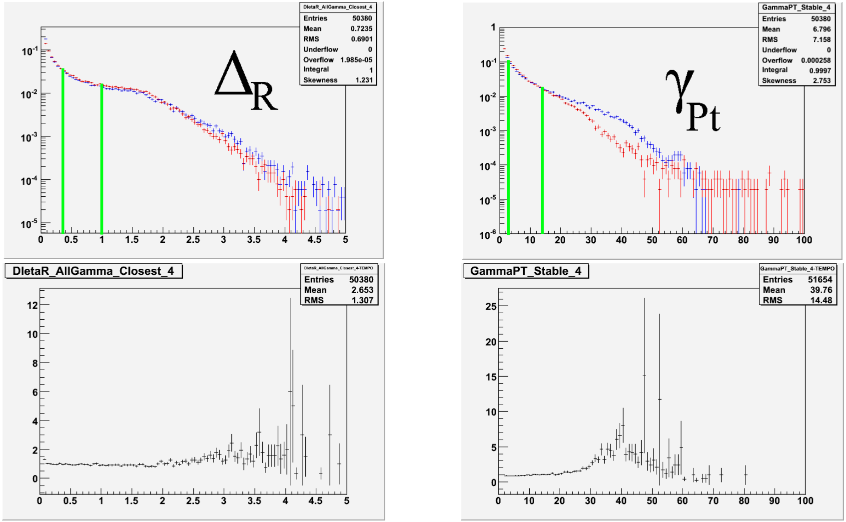
$M_{(W)} = 80.419, \Gamma_{(W)} = 2.4807653,$
$M_{(Z)} = 91.188, \Gamma_{(Z)} = 2.44194427, M_{(H)} = 120,$
$\Gamma_{(H)} = 0, g_W = 0.65323291,$
$\sin^2(\theta_W) = 0.222246533,$
$\frac{1}{aem \times (M_Z)} = 132.50698, m_t = 174.3,$
$m_b = 4.7, PDFset = CTEQ5L,$
$a_s(M_Z)[n_{loop} = 1] = 0.127003172$

Percentage of events surviving these cuts:

$Z \rightarrow \mu\mu$ Z0 : $\simeq 52K/500K \simeq 11\%$ with γ coming from `PYTHIA PS`

$Z \rightarrow \mu\mu + \gamma$ Z1 : $\simeq 50K/52K \simeq 96\%$ with γ coming from `ALPGEN ME`

Study results: stability zone & “robustness test points” choice I/VIII



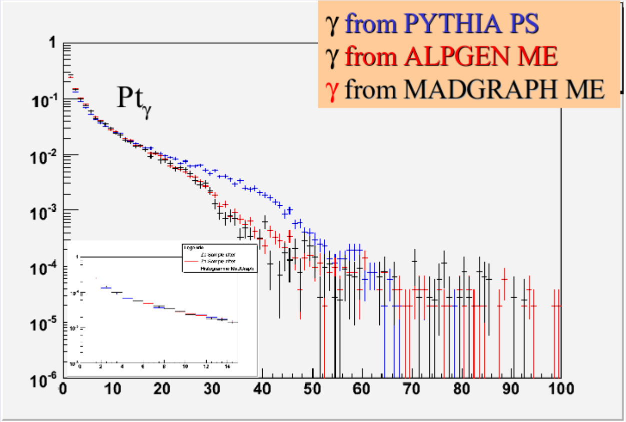
PYTHIA PS / ALPGEN ME (Δ_R) PYTHIA PS / ALPGEN ME (γ_{PT})

Observed zone of agreement between descriptions: Δ_R: $0.15 < \Delta_R(\gamma_{closest}, \mu) < 1.8$ γ_{PT}: $1 < \gamma_{PT} < 16$ GeV

Study results

Cross-check of the shape of the ME γ_{PT} distribution

Cross-check of the ALPGEN γ_{PT} distribution shape with MADGRAPH



Same generation parameters used for MADGRAPH as for ALPGEN. We have a good agreement between this two different matrix element generators.

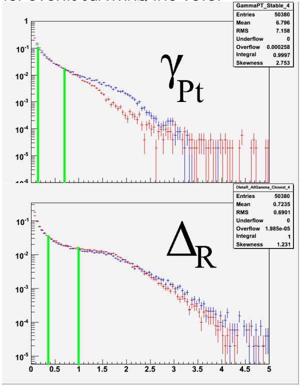
Study results

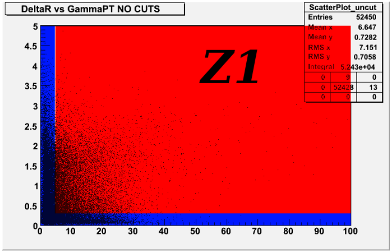
"Anti-double-counting veto" and robustness test strategy

Use veto procedure (using ALPGEN team prescription):

- Z_0 **keep** only events without any γ with $\Delta_R > \Delta_R$ Cut and $\gamma_{PT} > \gamma_{PT}$ Cut and $|\eta_\gamma| > \eta_\gamma$ Cut
- Z_1 **keep** only events with at least one γ with $\Delta_R > \Delta_R$ Cut and $\gamma_{PT} > \gamma_{PT}$ Cut and $|\eta_\gamma| > \eta_\gamma$ Cut

Examine the total X-section and shape of Z0 + Z1 for Δ_R and γ_{PT} for events surviving the veto.





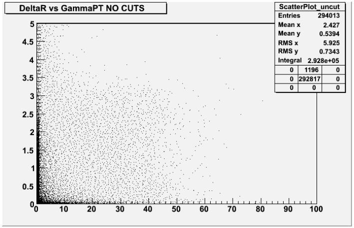
- Choose 4 cut points in the phase space within "agreement zone" in order to avoid edge biases:

Sample	Δ_R Cut	γ_{PT} Cut	$\lvert\eta_\gamma$ Cut $\rvert$
Point A	0.35	3 GeV	2.7
Point B	0.35	14 GeV	2.7
Point C	1.00	3 GeV	2.7
Point D	1.00	14 GeV	2.7

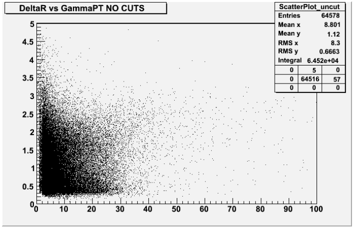
- Generation of the 4 Z1 dedicated samples.
- We applied the veto procedure on both Z0 and Z1 corresponding samples.

Study results

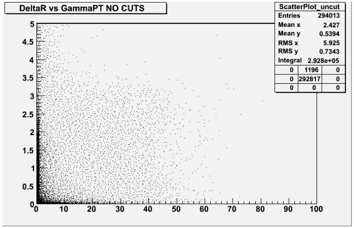
Independance of the studied vars



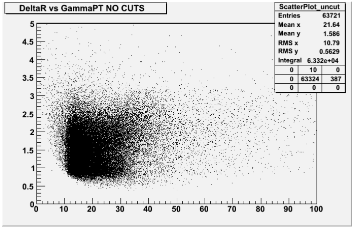
Sample Z0 Point A



Sample Z1 Point A



Sample Z0 Point D



Sample Z1 Point D

Study results

Results after veto: stability of total cross-section

Point	σ_{Z0_i}	σ_{Z0_f}
A	991.402 ± 0.514 fb	953.411 ± 0.494 fb
B	991.402 ± 0.514 fb	979.365 ± 0.508 fb
C	991.402 ± 0.514 fb	970.905 ± 0.503 fb
D	991.402 ± 0.514 fb	984.619 ± 0.510 fb

Cross-section for the different Z0 samples before and after veto

Point	Z_0	Z_1
A	3.832 %	28.2 %
B	1.214 %	29.5 %
C	2.067 %	37.1 %
D	0.684 %	36.0 %

Events rejected by veto double-counted in absence of veto

Point	σ_{Z1_i}	σ_{Z1_f}
A	41.34 ± 0.067 fb	29.683 ± 0.048 fb
B	9.056 ± 0.013 fb	6.381 ± 0.009 fb
C	24.51 ± 0.037 fb	15.421 ± 0.023 fb
D	5.619 ± 0.006 fb	3.594 ± 0.004 fb

Cross-section for the different Z1 samples before and after veto

Point	$\sigma_{Tot} = \sigma_{Z0_f} + \sigma_{Z1_f}$
A	**983.094** $\pm$ **0.542** fb
B	**985.746** $\pm$ **0.517** fb
C	**986.326** $\pm$ **0.526** fb
D	**988.213** $\pm$ **0.514** fb

TOTAL cross-section for the samples after veto

Remark: cross-section stability

The final cross-sections are compatible ($\approx 5\,^0/_{00}$) despite a small rising trend.

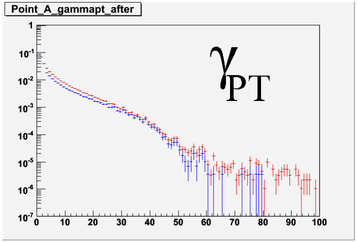
$\sigma_{Z0_i/Z1_i}$ = generation cross-section Z0 / Z1,

$\sigma_{Z0_f/Z1_f} = \sigma_{Z0_i/Z1_i} \times \frac{N_{total} - N_{veto}}{N_{total}}$,

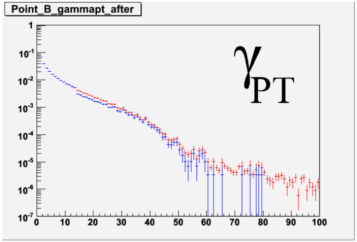
For Z1, the high percentage of vetoed events is an artifact of the difference between the “gen-level” and “match-level” cut values.

Study results

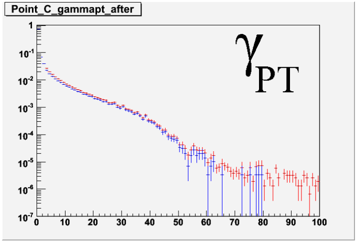
Distribution shape for γ_{PT} for Z0 and Z1



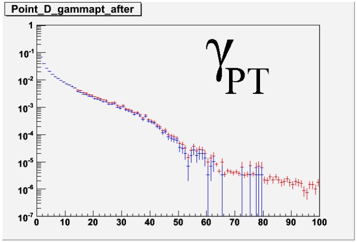
Plot for Point-A (γ_{PT})



Plot for Point-B (γ_{PT})



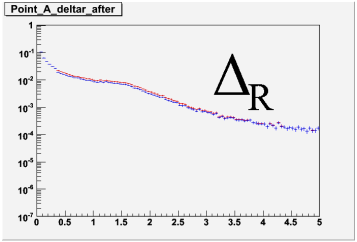
Plot for Point-C (γ_{PT})



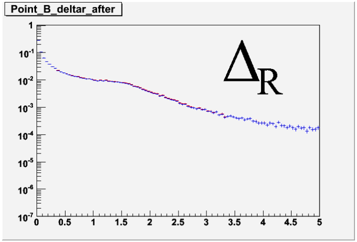
Plot for Point-D (γ_{PT})

Study results

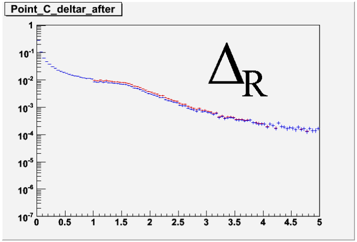
Distribution shape for Δ_R for Z0 and Z1 after veto



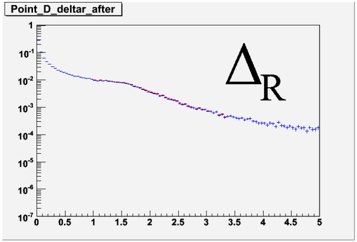
Plot for Point-A (Δ_R)



Plot for Point-B (Δ_R)



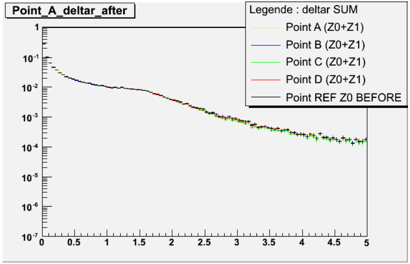
Plot for Point-C (Δ_R)



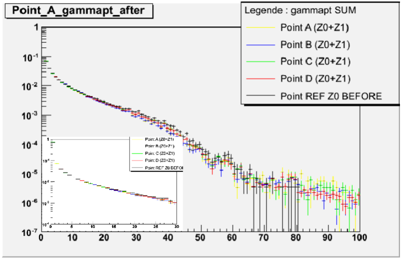
Plot for Point-D (Δ_R)

Study results

Robustness tests: distribution shapes for γ_{PT} & Δ_R



Shape comparison (Δ_R)



Shape comparisons (γ_{PT})

Distribution shapes γ_{PT} & Δ_R

- the curves for each study point are very similar (especially Δ_R) $\longrightarrow$ the veto can be based only on the γ_{PT} variable.
- For γ_{PT}, we observe a better agreement among the test points $A --> D$ than between them and the PS-photon-only reference curve before veto, particularly in the tails.

Remark : The `REF` curve used here contain only photons caming from `PYTHIA PS` generator before the veto.

Conclusions

For the moment, we have achieved the following:

1. Determined the phase space of observables where the ME/PS description differs. Δ_R & γ_{PT} OK
2. Determined the zone of validity where we can choose the "cutoff". OK
3. Check the robustness of the selected zone. OK
4. Choose the final cut maximizing the generation efficiency. Imminent

Conclusions:

- **Unexpected difference**: ME γ_{PT} distribution shape **cross-checked** with MadGraph
- **Order of magnitude of double-counting**: 0.7 – 4% depending on position of cutoff within the zone of agreement. Veto is needed to allow double-counting less thant 0.5% in the region near the border of the zone of agreement.
- **Stability of the cross-section after veto**: the cross-section is stable within $\approx 5\,^0/_{00}$ with a small rising trend.
- **Stability of the Δ_R distribution shape**: the stability of the shape of Δ_R between PS and PS/ME combined distributions before versus after veto leads to the conclusion that it could be dropped as a veto variable.
- **Stability of the γ_{PT} distribution shape** : The curves for each study point are compatible (within statistical errors).There is a significant difference between the distributions of PS-only γ before veto and the distributions for the 4 PS/ME combined samples after veto.

Prospects

- **Extension to other explicit γ orders**: $Z + 2\gamma$, $Z + 3\gamma, \ldots$
- **Extension to other channels that are potentially affected by EM double-counting**: $m\gamma + njets$, $W + n\gamma + mjets, \ldots$ m γ + n jets In progress
- **Implementation in ALPGEN** of the EM PS/ME matching, test version for m γ + n jets process made by authors and thought to be given to us soon for testing.

Thanks : We want to thank the **ALPGEN** team for their help, especially for their inclusion of the $Z + \gamma$ (into a private version `2.11`) and their work for the inclusion of PS/ME tools in their "work in progress" version.

Backup slides

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