Preparatory study for QED ME/PS matching

C. Bâty S. Gascon M. Lethuillier
(IPNL, Université Lyon 1, Université de Lyon)
J. Tao
IHEP (Beijing)
M. Moretti F. Piccinini R. Pittau
(Univ. Ferrara/INFN, Univ. Pavia/INFN, Univ. Torino/INFN & Univ. Grenada)

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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.

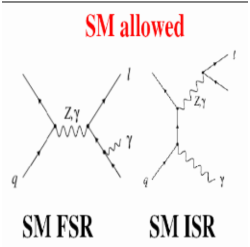
Goal:

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: $Z \rightarrow \mu\mu + \gamma$**, its relevances 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).



Study presentation

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 $Z \longrightarrow \mu\mu$, 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.

Study presentation

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- Second, we use ALPGEN to generate process $Z \rightarrow \mu\mu + \gamma$ 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"
- Check the robustness of this range under the "anti-double-counting veto" (to be describe 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 $\Delta_R > 0.05$ & $PT_{\mu\mu} > 1GeV$ & $|\eta| < 3.0$
- Both samples are normalized to one.

Generation parameters

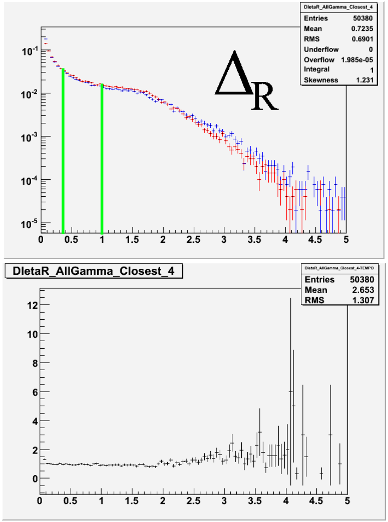
$M_{(W)} = 80.419$, $\Gamma_{(W)} = 2.4807653$, $M_{(Z)} = 91.188$, $\Gamma_{(Z)} = 2.44194427$, $M_{(H)} = 120$, $\Gamma_{(H)} = 0$, $g_W = 0.65323291$, $\sin^2(\theta_W) = 0.222246533$, $\frac{1}{a_{em} \times (M_Z)} = 132.50698$, $m_t = 174.3$, $m_b = 4.7$, $PDFset = CTEQ5L$, $a_s(M_Z)[n_{loop} =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

Percentage of events surviving these cuts:

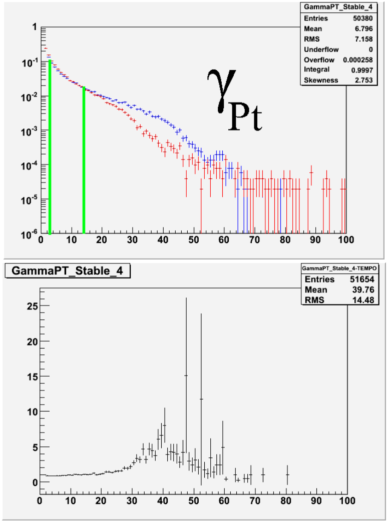
$Z \rightarrow \mu\mu$ Z0 : $\simeq 52K/500K \simeq 11\%$ with γ coming from `PYTHIA PS`

$Z \rightarrow \mu\mu + \gamma$ 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)



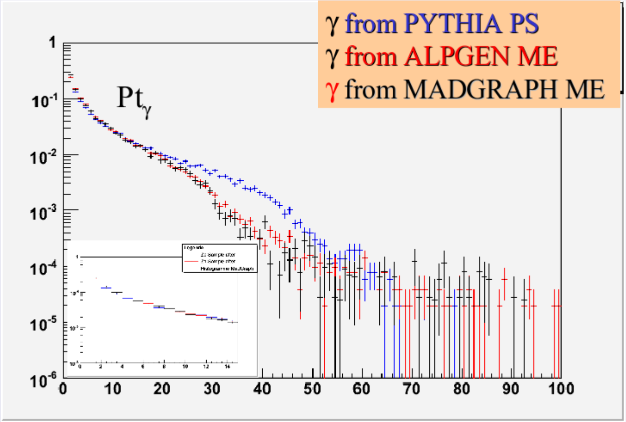
PYTHIA PS / ALPGEN ME (γ_{PT})

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

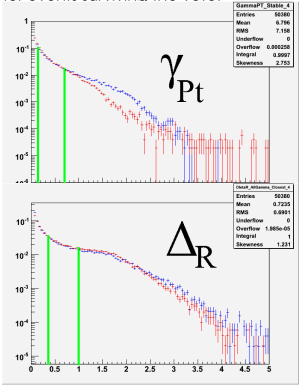
III/VIII

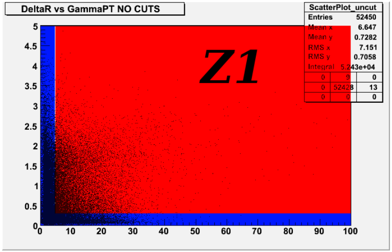
"Anti-double-counting veto" and robustness test strategy

Use veto procedure (using `ALPGEN` team prescription):

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





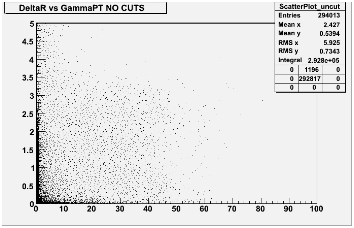
- Choose 4 cut points in the phase space within "agreement zone" in order to avoid edge biases:

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

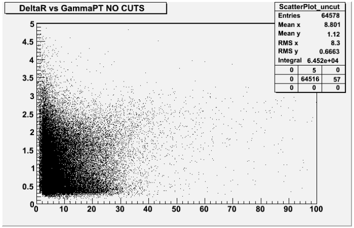
- Generation of the 4 Z1 dedicated samples.
- We applied the veto procedure on both Z0 and Z1 corresponding samples.

Study results

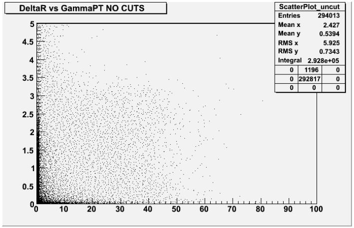
Independance of the studied vars



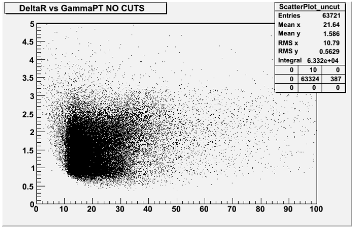
Sample Z0 Point A



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

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

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

Remark: cross-section stability

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

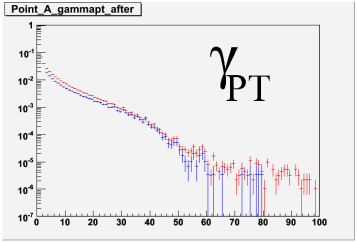
$\sigma_{Z0_i/Z1_i}$ = generation cross-section Z0 / Z1,

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

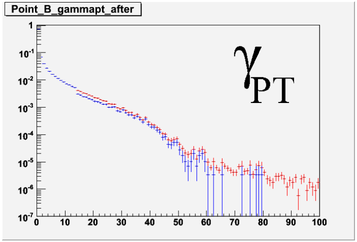
For Z1, the high percentage of vetoed events is an artifact of the difference between the “gen-level” and “match-level” cut values.

Study results

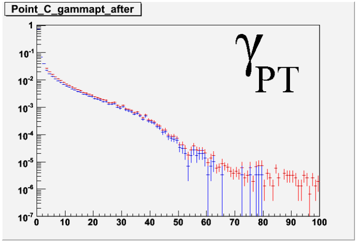
Distribution shape for γ_{PT} for Z0 and Z1



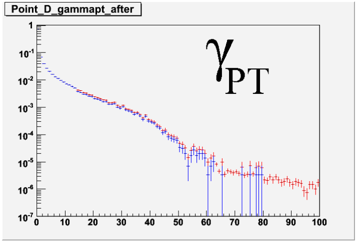
Plot for Point-A (γ_{PT})



Plot for Point-B (γ_{PT})



Plot for Point-C (γ_{PT})

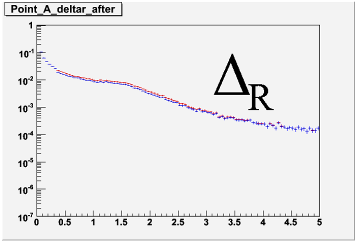


Plot for Point-D (γ_{PT})

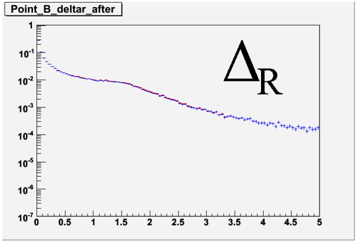
Study results

VII/VIII

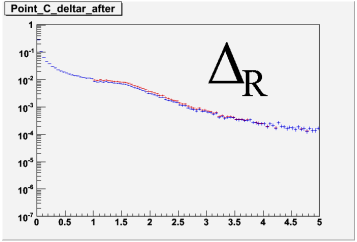
Distribution shape for Δ_R for Z0 and Z1



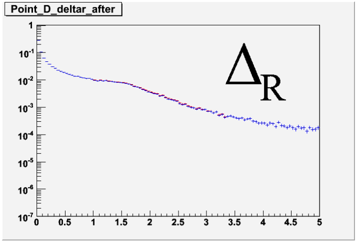
Plot for Point-A (Δ_R)



Plot for Point-B (Δ_R)



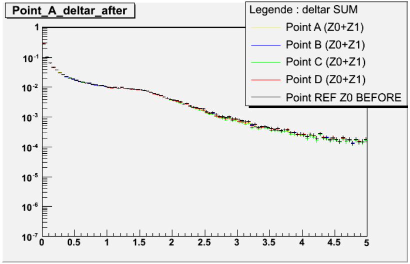
Plot for Point-C (Δ_R)



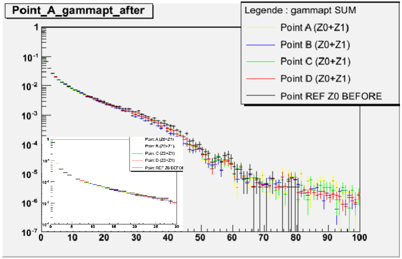
Plot for Point-D (Δ_R)

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. $\boxed{\Delta_R \text{ \& } \gamma_{PT} \text{ OK}}$
2. Determined the zone of validity where we can choose the "cutoff". $\boxed{\text{OK}}$
3. Check the robustness of the selected zone. $\boxed{\text{OK}}$
4. Choose the final cut maximizing the generation efficiency. $\boxed{\text{Imminent}}$

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**: $m\gamma + njets$, $W + n\gamma + mjets, \ldots$ $\boxed{\text{m } \gamma \text{ + n jets In progress}}$
- **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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