Inclusive photon production at forward rapidities for pp and p-pb collisions in ALICE at the LHC

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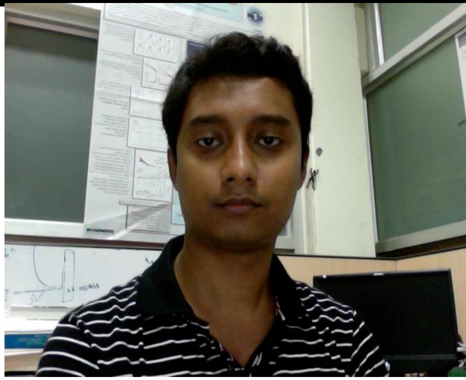


OUTLINE

p-p collisions

- Introduction
- Effects of the upstream material in front of the PMD
- Analysis details
- Results and discussions
- Summary

Link of the Analysis Note **:** *https://aliceinfo.cern.ch/Notes/node/149 (Sudipan De and Subhash Singha)*

p-Pb collisions

- Data taken by PMD in p-Pb collisions
- QA plots
- Analysis details
- Results and discussions
- Summary and To do lists

Introduction

Inclusive photons are measured at forward rapidities ($2.3<\eta<3.9$) with the ALICE experiment for proton-proton collisions at LHC energies.

Using these measurements, following physics issues can be addressed:

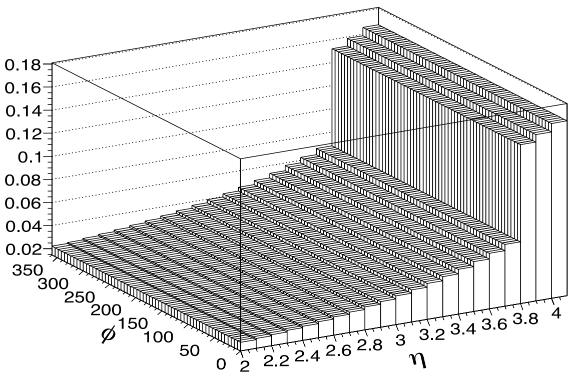
- The beam energy dependence of photon multiplicity at forward rapidity
- Limiting fragmentation behavior in proton-proton collisions
- Study of azimuthal correlations
- Along with the charged particle measurements in Forward Multiplicity Detector (FMD) of ALICE, charge-neutral correlations can be studied.

These measurements provide a good baseline for heavy-ion collisions at LHC.

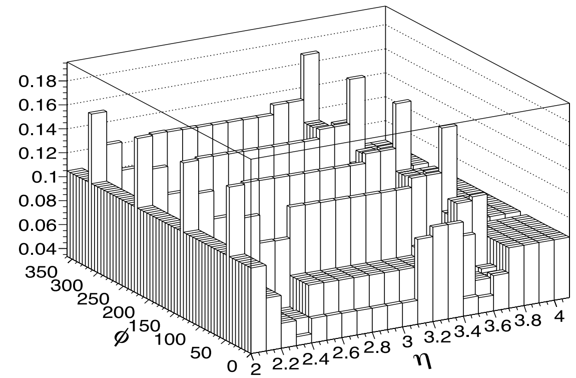
Upstream material in front of PMD

AliRoot v4-21-25-AN
Z = 360 cm ,δη = 0.1, δϕ = 6 degree

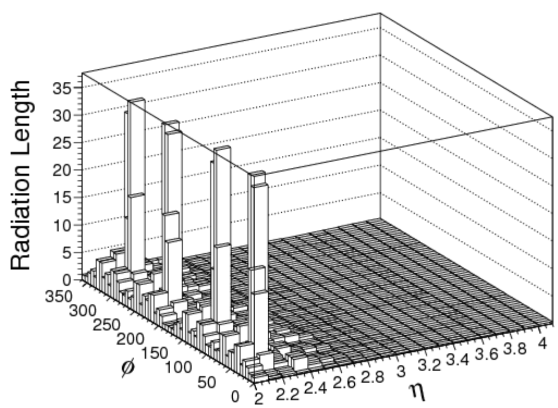
Beam pipe



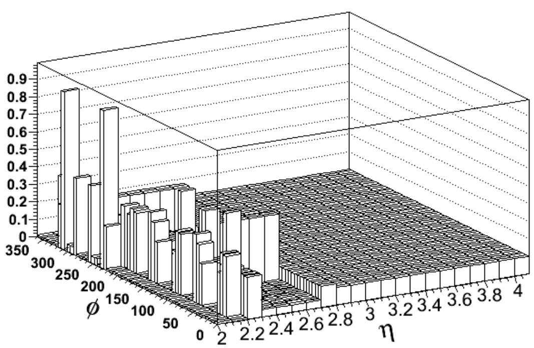
FMD (2.28 < η < 3.68)



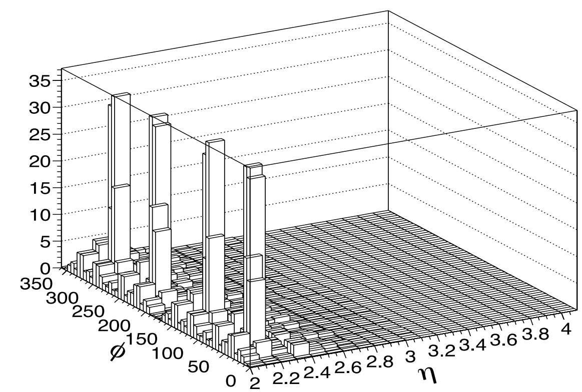
All detectors



V0 (2.8 < η < 5.1)



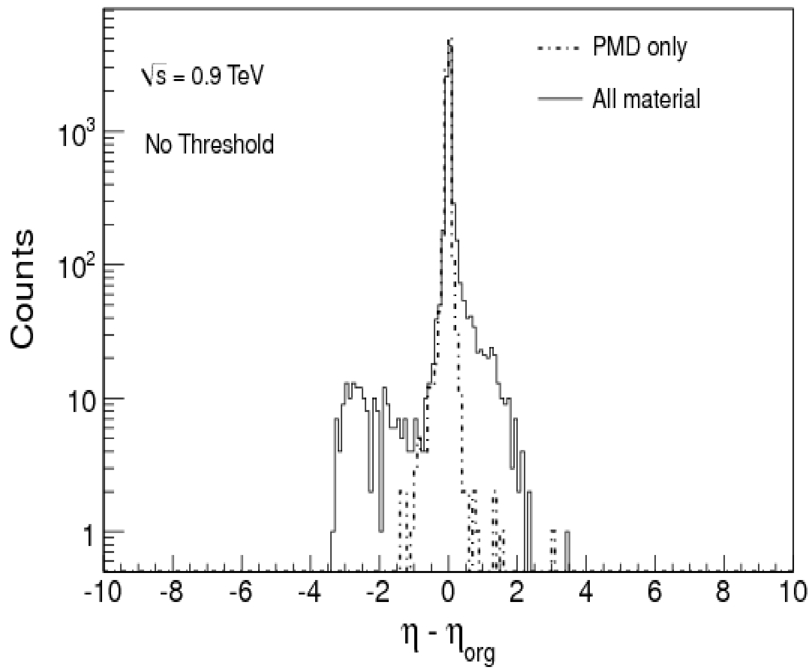
ITS(2.8 < η < 5.1**)**

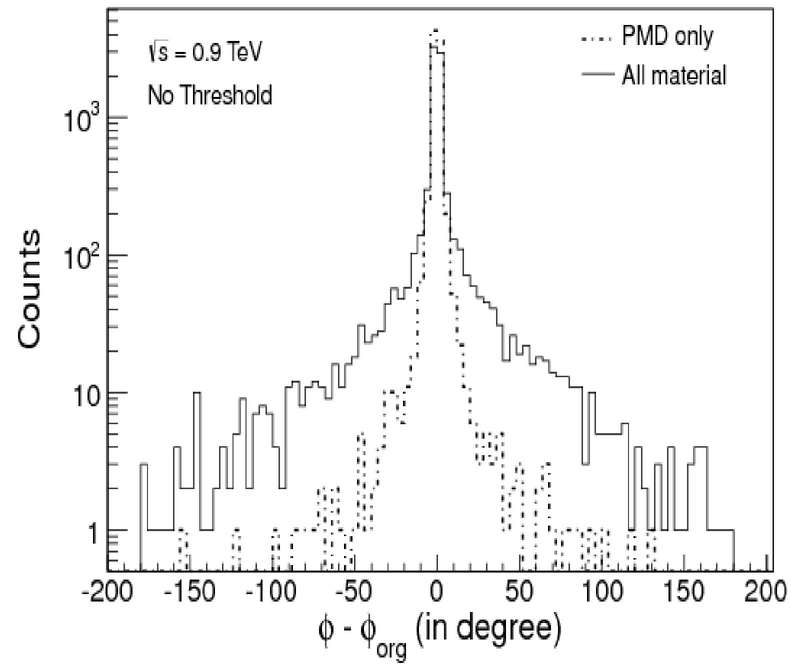


Deflection of the measured track from the original

ALL CLUSTERS (NO Threshold)

$h - h_{org}$ $f - f_{org}$





η_{org}, ϕ_{org} -> Original photon tracks or incident photon tracks

η, ϕ -> detected photon tracks after passing through Geant

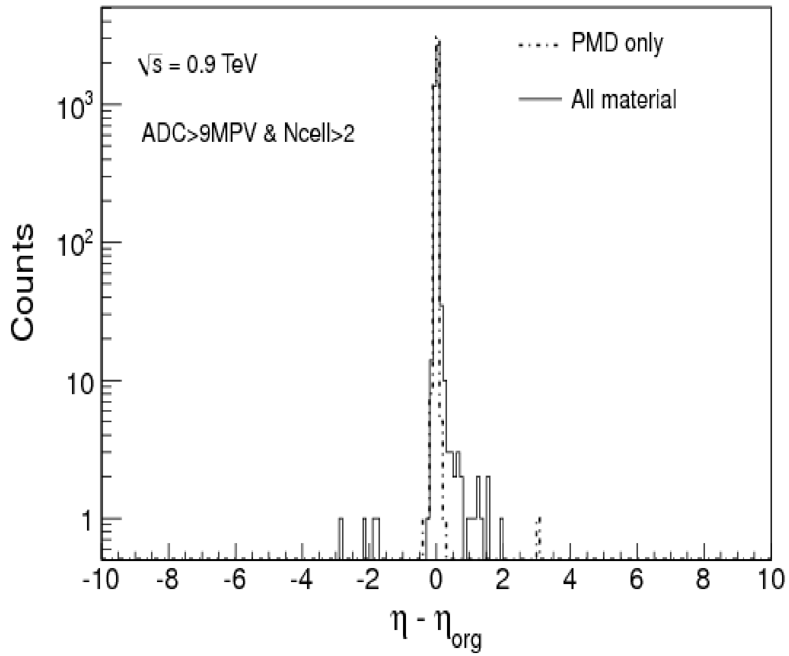
Comparison: PMD Only and PMD with All Materials as in Aliroot

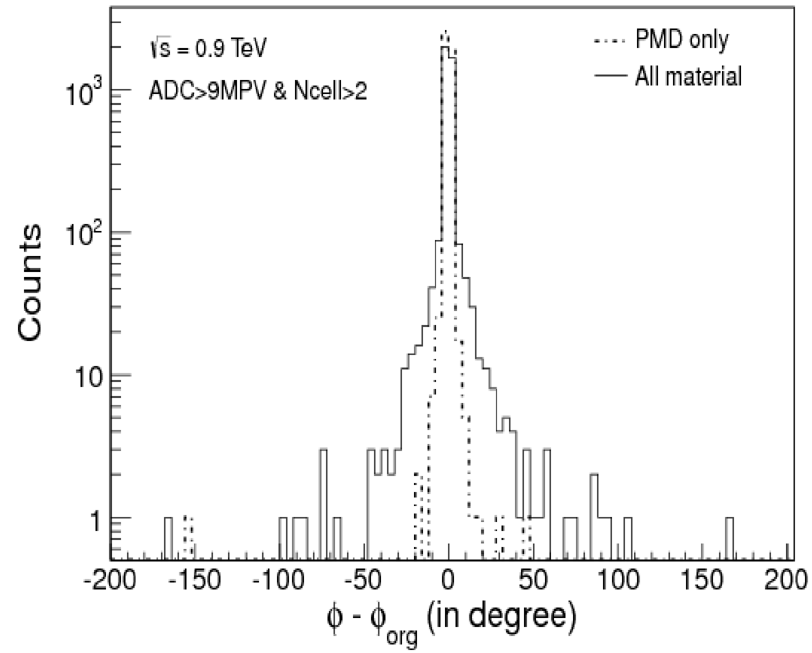
Large deviations are observed corresponding to material in front

Deflection of the measured track from the original

γ-like CLUSTERS (WITH Threshold)

$h - h_{org}$ $f - f_{org}$

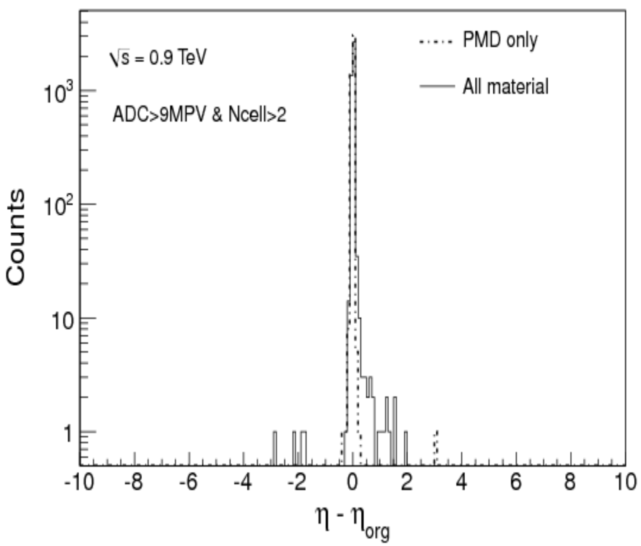


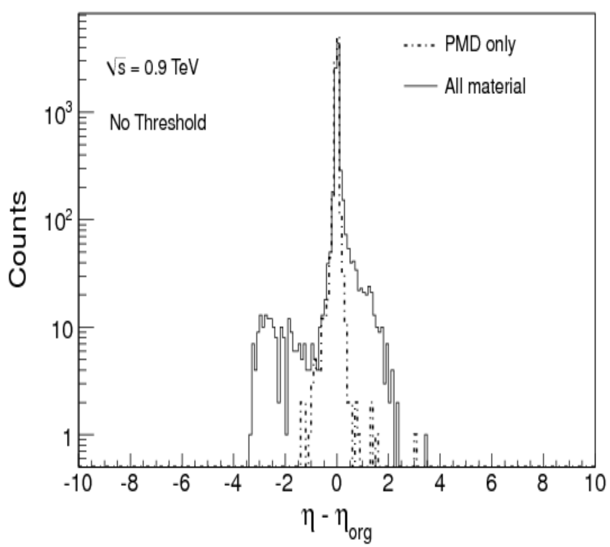


η_{org}, ϕ_{org} -> Original photon tracks or incident photon tracks
η, ϕ -> detected photon tracks after passing through Geant

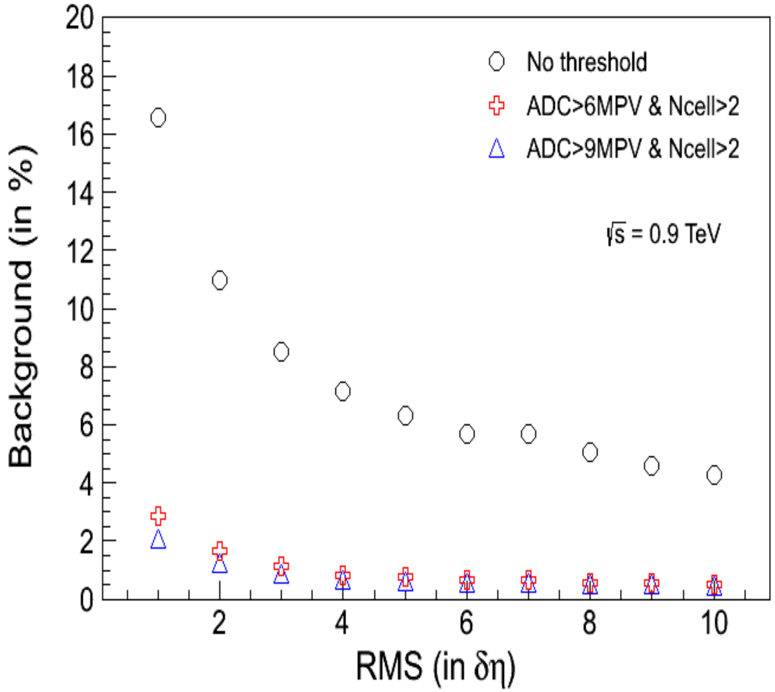
- **With Photon Detection threshold the amount of deviation from the original track is reduced to a large extent.**

Estimation of background due to material





We take the PMD only case. With the increase of rms, the percentage of area outside the curve gives an estimation of background from upstream materials. With threshold, the background from upstream is minimized.



Contribution from upstream material:

Without threshold: background is about ~16%
With THRESHOLD: background is about ~3%

Charged particle contamination

Most of the charged particles are minimum ionizing particles and hit one or two cells. ADC values of charged particles clusters are lower than that of photon clusters since photons produce shower and hit more than one cells

We have applied a threshold of ADC and ncell to discriminate charged particles from Photons

$\mathbf{N_{clus}}$: Cell Hits are clustered on the Preshower Plane. N_{clus} gives the total number of clusters

$\mathbf{N_{\gamma\text{-like}}}$: Number clusters above thresholds on number of cells and Cluster ADC. It contains

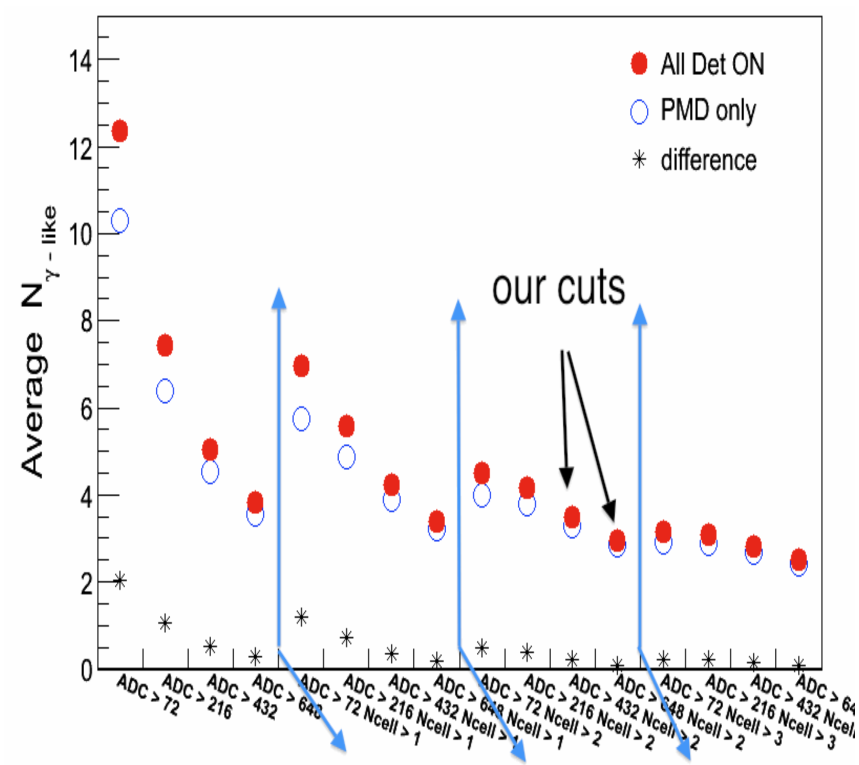
- Split clusters of photons
- Charged particles which pass our threshold cuts
- Charged particle contamination from upstream material

$\mathbf{N_{\gamma\text{-det}}}$ **:** Number of Clusters above thresholds from primary photons

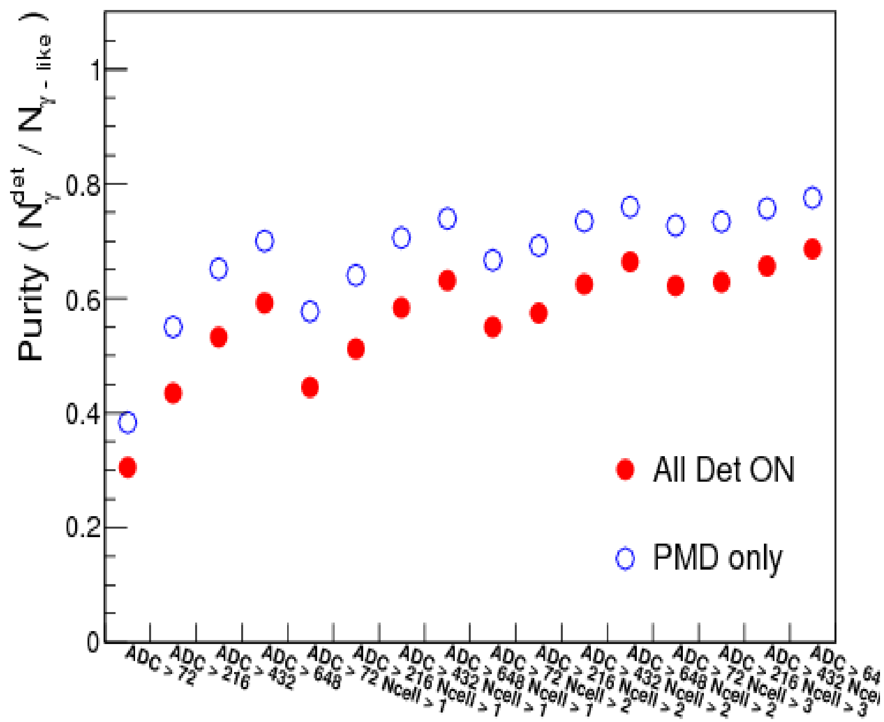
We define a quantity purity = $\mathbf{N_{\gamma\text{-det}} / N_{\gamma\text{-like}}}$ and see how it behaves with different thresholds for both PMD in air and PMD with all material cases.

Charged particle contamination

Average $N_{\gamma\text{-like}}$



Purity ($N_{\gamma\text{-det}}$ / $N_{\gamma\text{-like}}$)



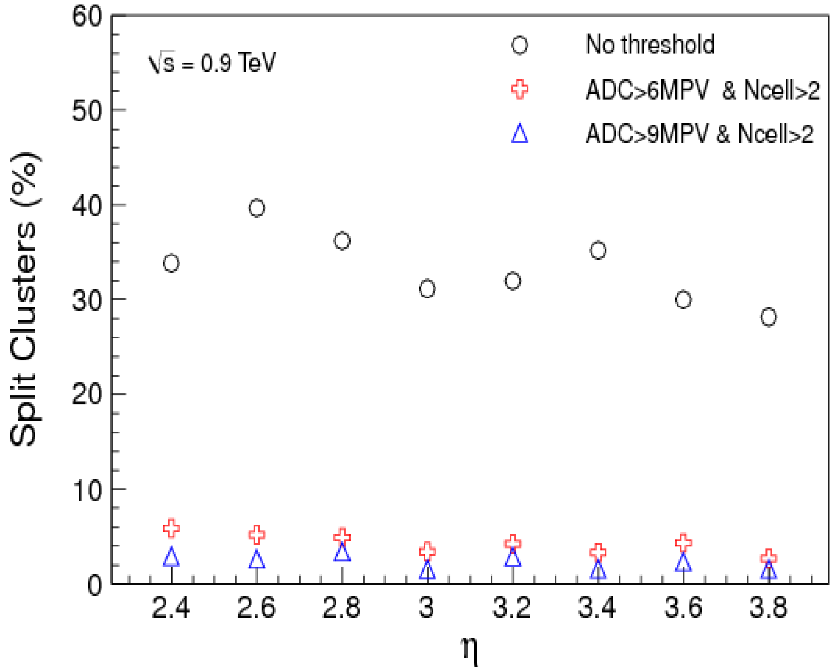
With application of the threshold the number of clusters for PMD with all detectors becomes close to PMD only and also the purity increases. That means the effect of background from upstream gets reduced.

Split clusters study

- Usually one photon track produces one cluster in preshower plane. Each cluster is then tagged by the track number corresponding to the incident photon. In some cases we have found that some clusters have same track number. In these cases the cluster with highest ADC is called as the main cluster and rest are termed as split clusters.

- The split clusters arise because of the photon conversion in lead and also from upstream materials.

- After applying photon-hadron discrimination threshold the percentage of split clusters are significantly reduced.



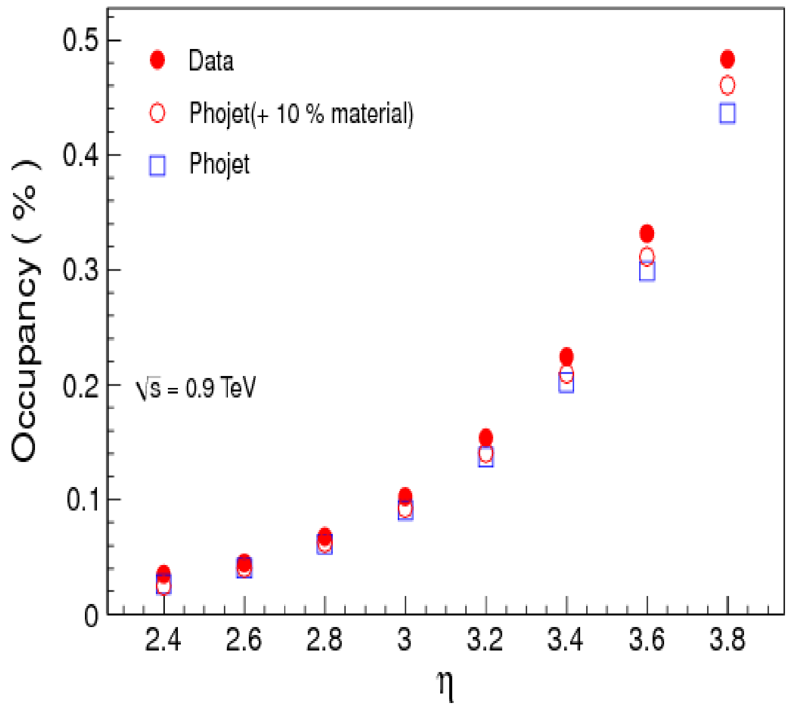
Occupancy

Occupancy is an indicator of how well the simulations describe the LHC data

$$\text{Occupancy (\%)} = \frac{\text{Number of hit cells in an } \eta \text{ bin}}{\text{Number of cells available in an } \eta \text{ bin}} \times 100$$

- LHC data is compared to PHOJET and PHOJET+10% material (LHC11d4a).
- Occupancy for PHOJET + 10% material (LHC11d4a) is comparable to data

  This PHOJET + 10 % data set is used to estimate the systematic errors in our Results.



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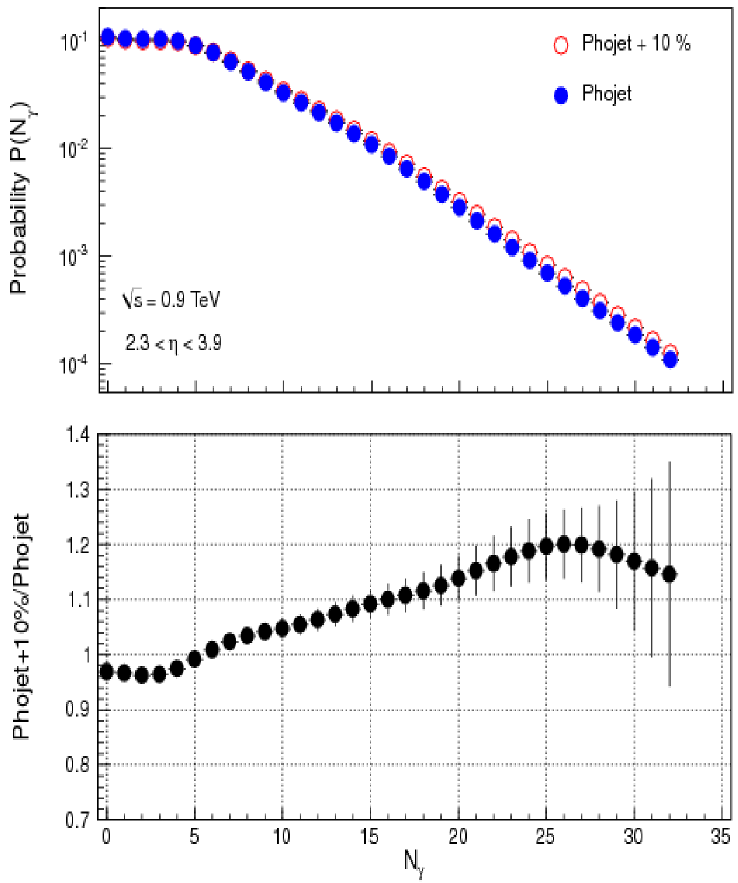
Systematic uncertainty due to material

We have taken Response Matrix from Normal PHOJET

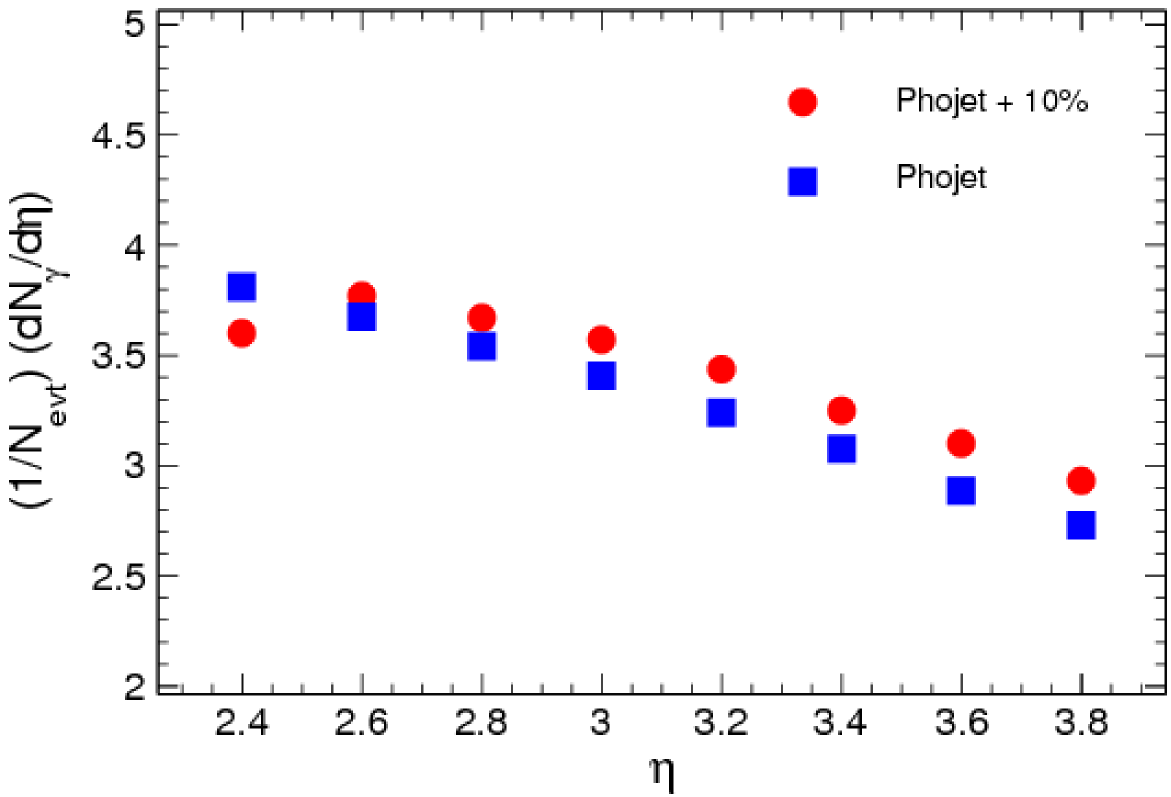
Unfold the measured multiplicity (passing through GEANT) of PHOJET +10 %

Unfold the measured multiplicity (passing through GEANT) Of normal PHOJET

The ratio between two unfolded distribution is taken as systematic uncertainty.



Systematic uncertainty due to material



Maximum difference between the two is used as a systematic uncertainty in dN/dη (which is ~7%).

Systematic uncertainties (different sources)

– Upstream Material (All ready discussed).

– Effect of discrimination thresholds Two different sets of thresholds are applied:
(a) Cluster ADC>432 (6 times the MPV value of MIP) and ncell>2
(a) Cluster ADC>648 (9 times the MPV value of MIP) and ncell>2
The differences in the extracted photon multiplicity is assigned as systematic errors.

– Unfolding using different event generators
Here PYTHIA and PHOJET event generators are used for unfold the data and the difference between the unfolded distributions are taken as uncertainties.

– Unfolding using different method : X^2 minimization and Bayesian

– systematic error in the zero bin (the bin with zero multiplicity) is large due to the trigger efficiency correction.

Systematic uncertainties in multiplicity

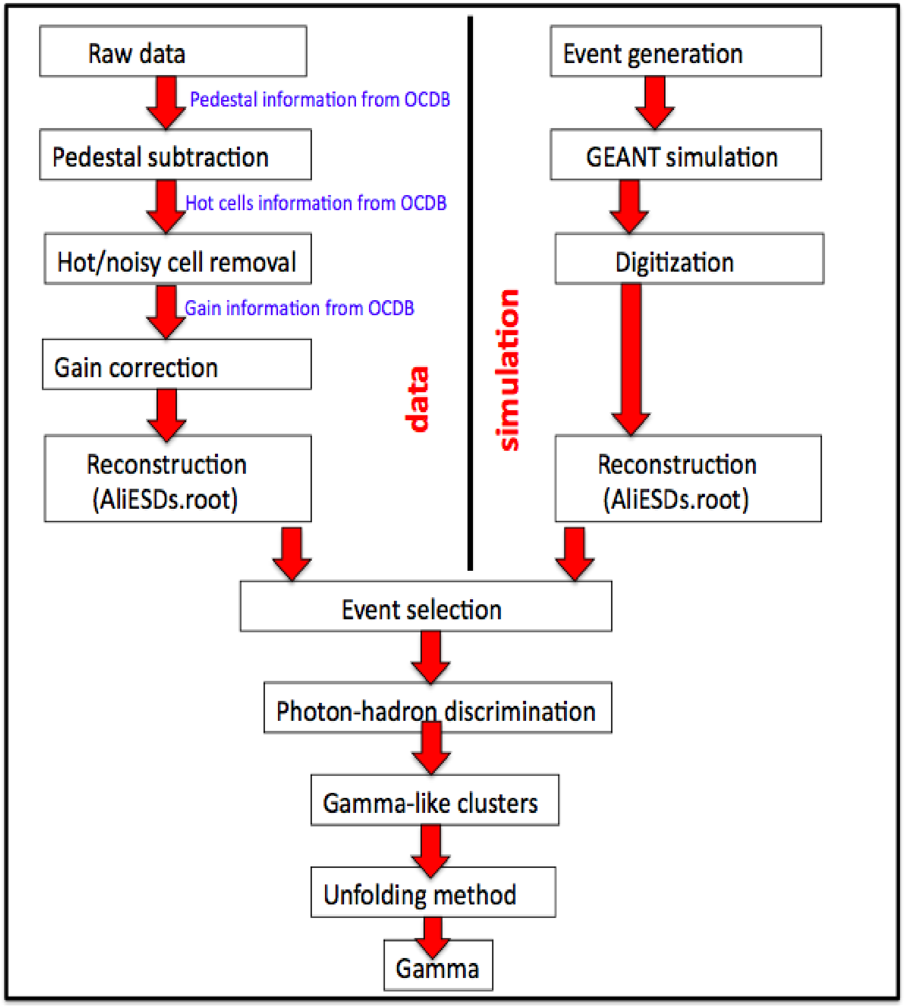
Source	0.9 TeV (0-10)	2.76 TeV(0-10)	7 TeV(0-10)
Effect of upstream materials	3 - 5%	3 - 5 %	3 - 5 %
Discrimination threshold	0.1 - 2.5 %	0.1 – 0.8 %	0.15-1.5 %
Method of unfolding (Event generator)	0.12 – 7.5 %	0.27– 7.7 %	0.17 – 8.6%
Method of unfolding	0.18 – 2.5 %	1.8 –3.7 %	0.06- 4.7 %
Total	18%(0-bin) 3 - 9.6%	9%(0-bin) 3.5 – 9.8%	14%(0-bin) 3 – 9.2%

Systematic uncertainties in pseudoraidity distribution

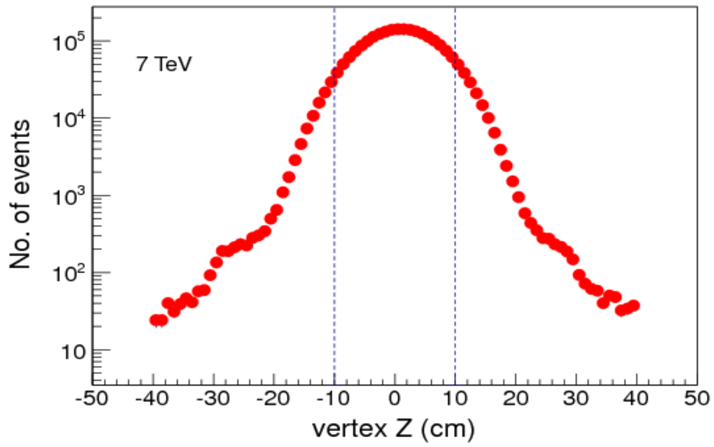
Source	0.9 TeV	2.76 TeV	7 TeV
Effect of upstream materials	7%	7 %	7%
Discrimination threshold	2 %	1 -2 %	1 - 2 %
Method of unfolding (Event generator)	1 – 3%	1– 2 %	3.6 – 7 %
Method of unfolding	negligible	negligible	negligible
Total	7 – 7.9%	7 -7.5%	8 -10%

Analysis method

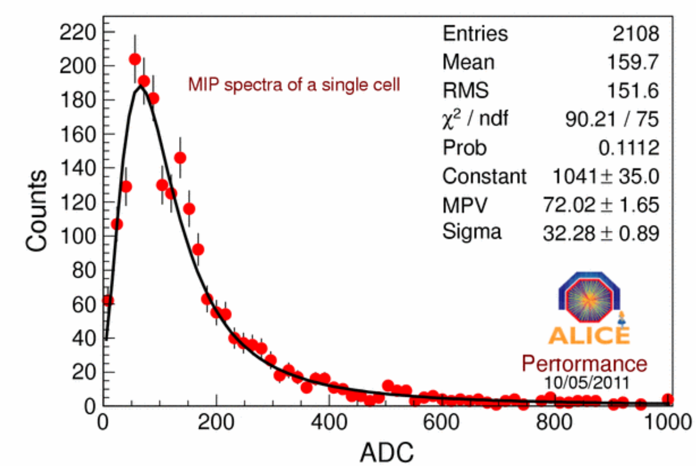
Analysis flow chart



Vertex Z

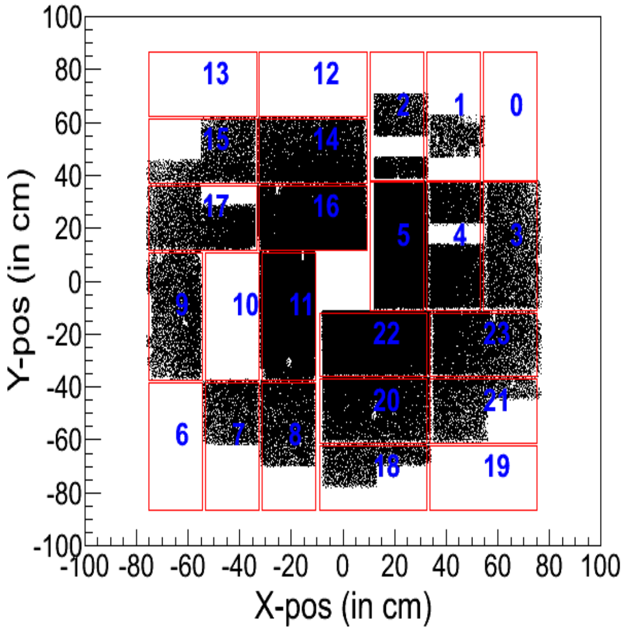


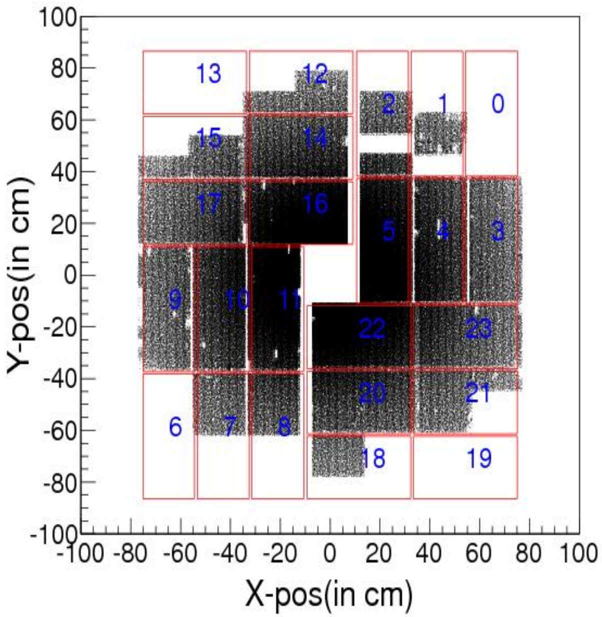
MIP spectra

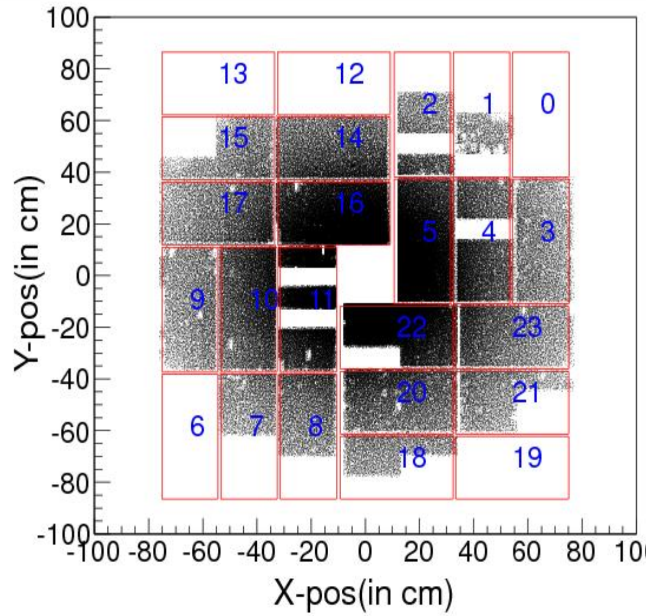


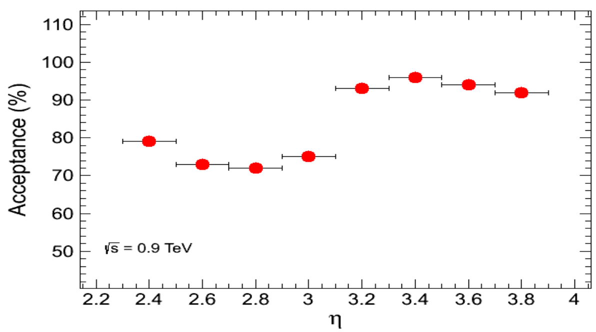
Acceptance

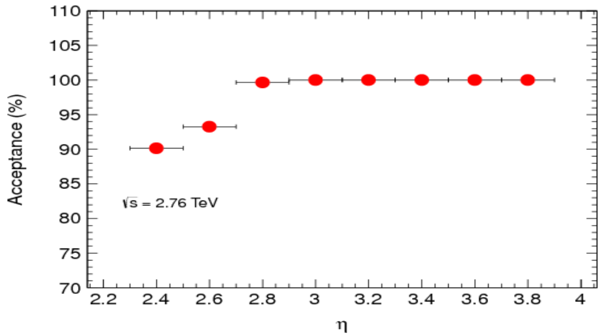
0.9 TeV	2.76 TeV	7 TeV

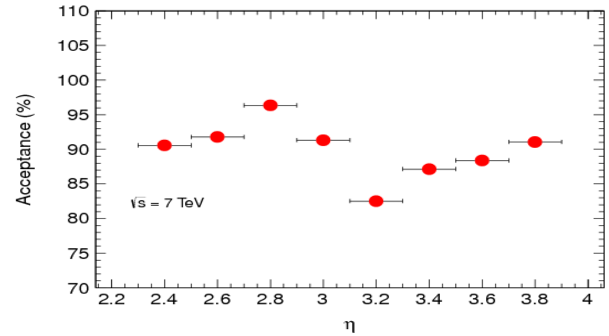






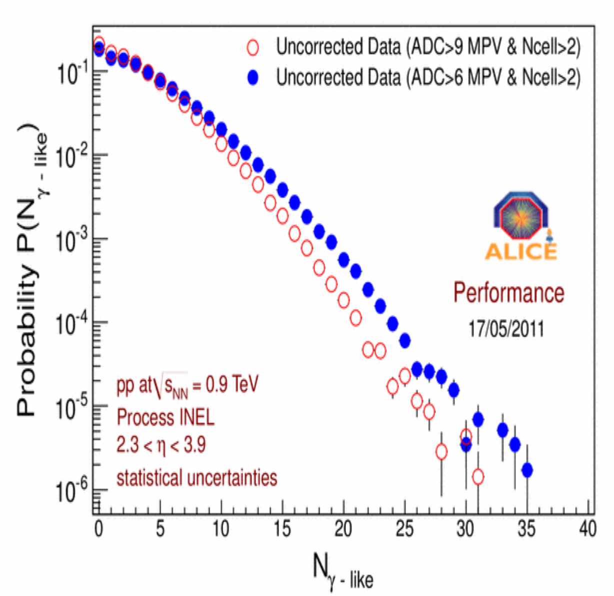




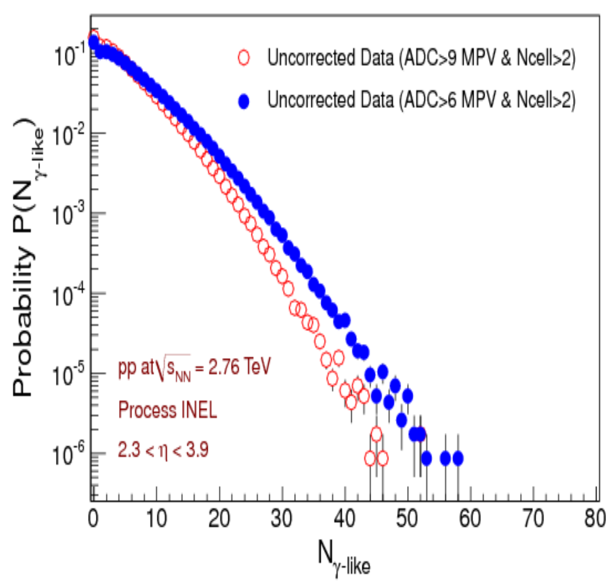


Uncorrected Photon multiplicity

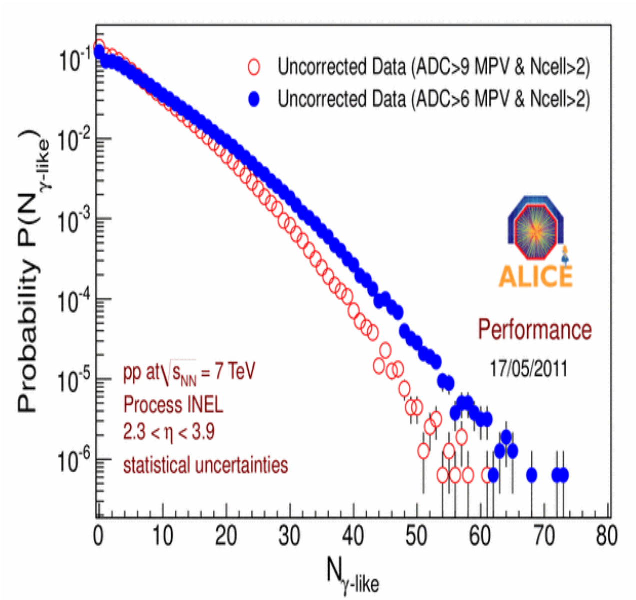
0.9 TeV



2.76 TeV



7 TeV



- Photon hadron discrimination threshold is applied to get $N_{\gamma\text{-like}}$ distribution
- $N_{\gamma\text{-like}}$ distribution are shown for two different thresholds for all the energies
- Unfolding method is used to get correct photon multiplicity (N_{γ})

Correction using simulation

This is the determination of true multiplicity from measured multiplicity using a detector response matrix

$$\hat{g} = A\hat{f} \quad \longrightarrow \quad \hat{f} = A^{-1}\hat{g}$$

f = true distribution
g = measured distribution
A = detector response matrix

Using minimization of a χ^2-function given as:

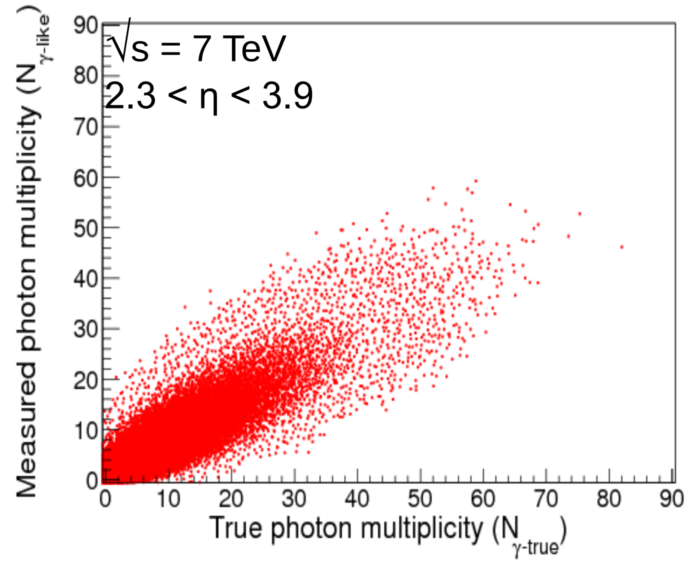
$$\hat{\chi}^2 = \sum_i \left(\frac{g_i - \sum_j A_{ij} f_j}{e_i}\right)^2$$

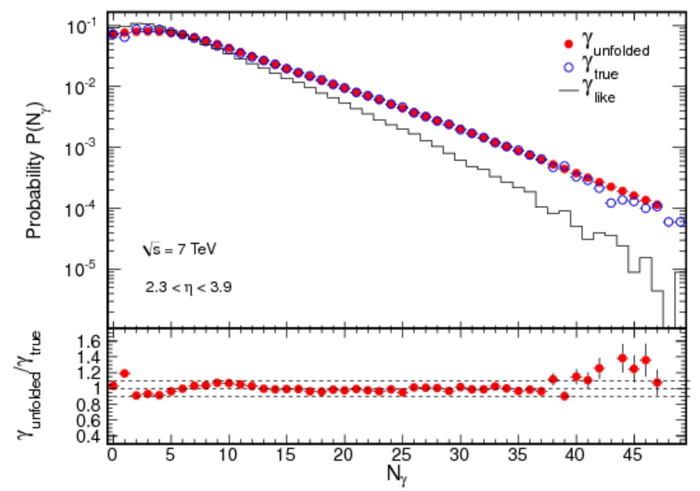
where 'e_i' is the error in measurement, and adding a regularization term P,

$$\chi^2 = \hat{\chi}^2 + \beta P$$

Where β is weight factor, the oscillations in the solutions are removed.

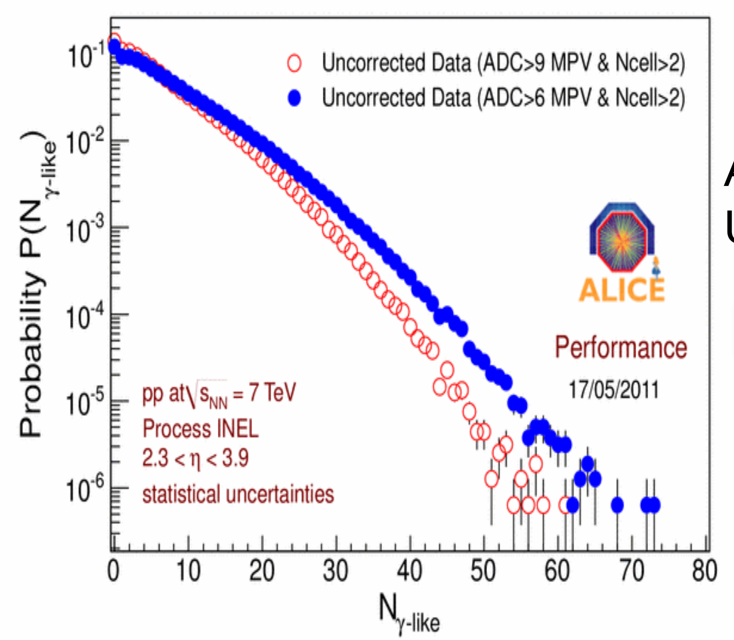
Response Matrix





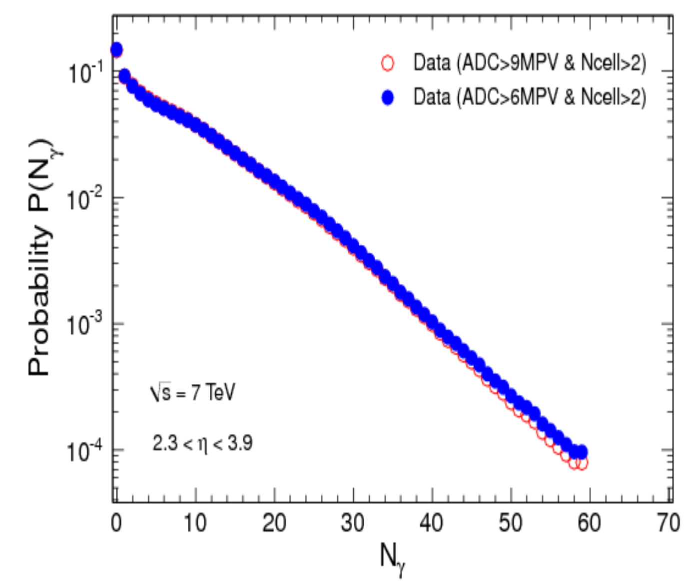
Correction using simulation

Uncorrected distribution



After correction
Using response matrix

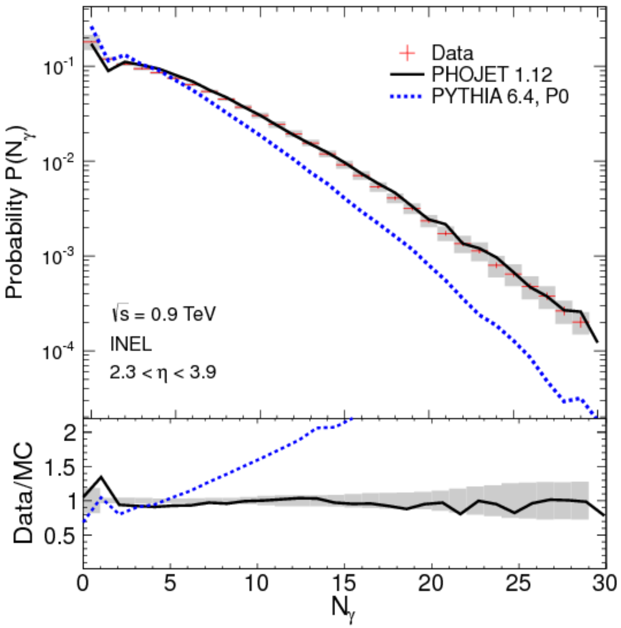
corrected distribution



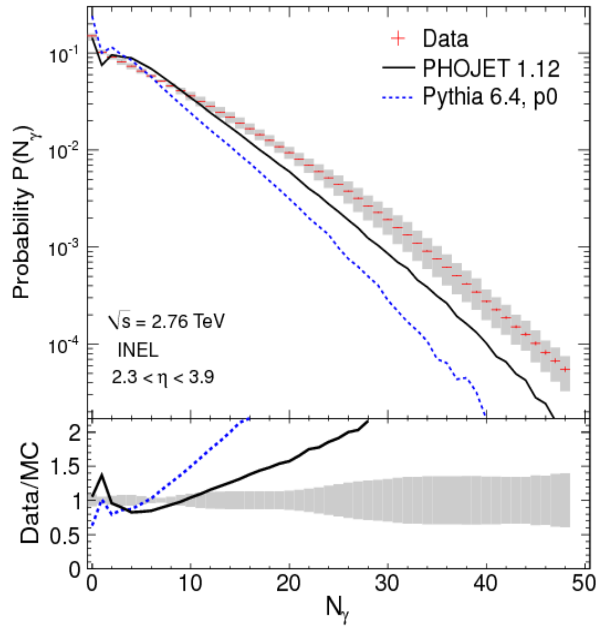
➢ After unfolding corrected multiplicity distribution is similar for two different threshold.

Corrected photon multiplicity distribution

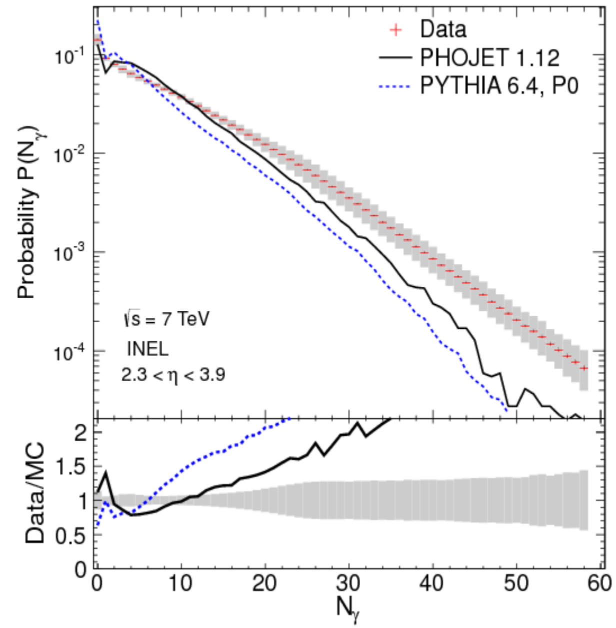
0.9 TeV



2.76 TeV



7 TeV

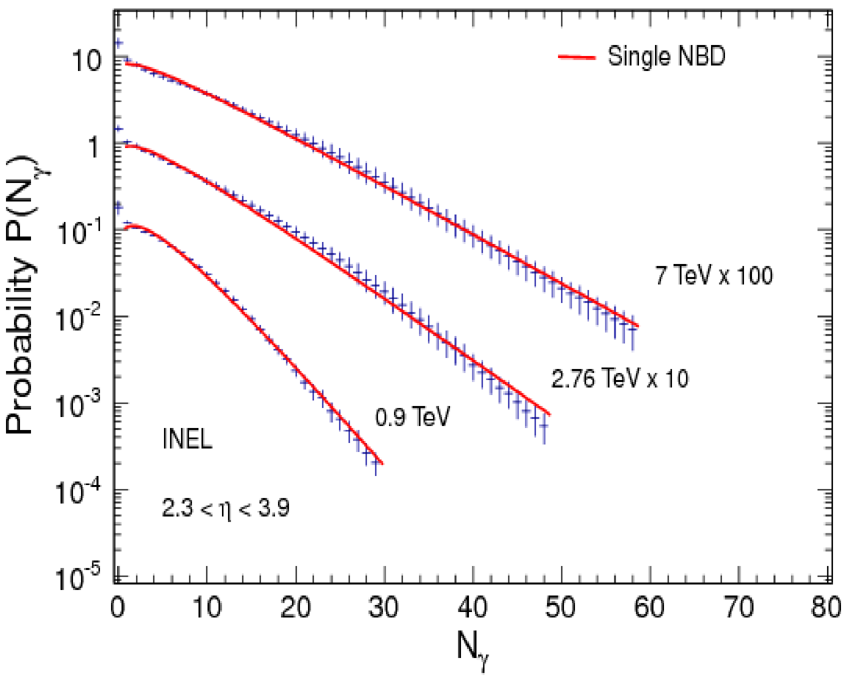


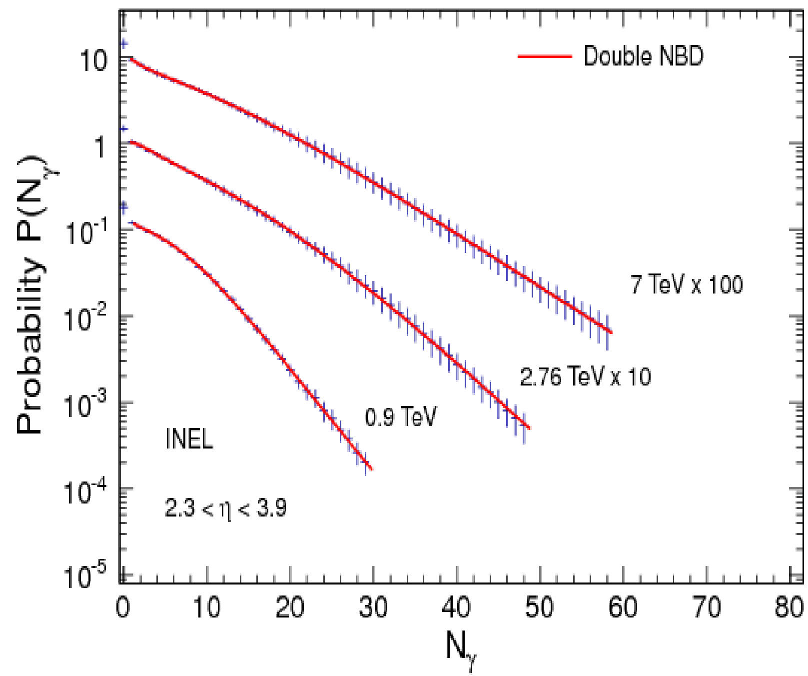
- 0.9 TeV: PHOJET comparable to data whereas PYTHIA under predicts the data
- 2.76 TeV: PHOJET comparable to data whereas PYTHIA under predicts the data
- 7 TeV: PHOJET and PYTHIA both under predict the data.

Fitted With NBD

Single NBD

Double NBD





$1/k \rightarrow 0$: Poissonian distribution
$k \rightarrow 1$: Geometric distribution
$n \rightarrow$ Average photon multiplicity

NBD parameters

Single NBD:

$\sqrt{s}$ in TeV	k	m	X^2/ndf
0.9	1.72 ± 0.06	5.14 ± 0.07	20.87/26
2.76	1.33 ± 0.05	7.05 ± 0.14	29.46/45
7	1.22 ± 0.04	8.48 ± 0.15	14.67/55

Double NBD:

$\sqrt{s}$ in TeV	k (k1,k2)	m(m1,m2)	W	X^2/ndf
0.9	2.73 ± 0.13, 0.55 ± 0.31	6.22 ± 0.29 2.46 ± 0.66	0.57 ± 0.26	0.72/23
2.76	3.66 ± 0.50 1.26 ± 0.24	12.56 ± 0.69 4.35 ± 0.24	0.34 ± 0.01	0.61/42
7	2.75 ± 0.31 0.88 ± 0.11	13.02 ± 1.24 6.56 ± 0.424	0.28 ±0.006	0.26/52

Beam energy dependence

NSD result (to compare with UA5) obtained from measured ALICE INEL data using PYTHIA

0.9 TeV

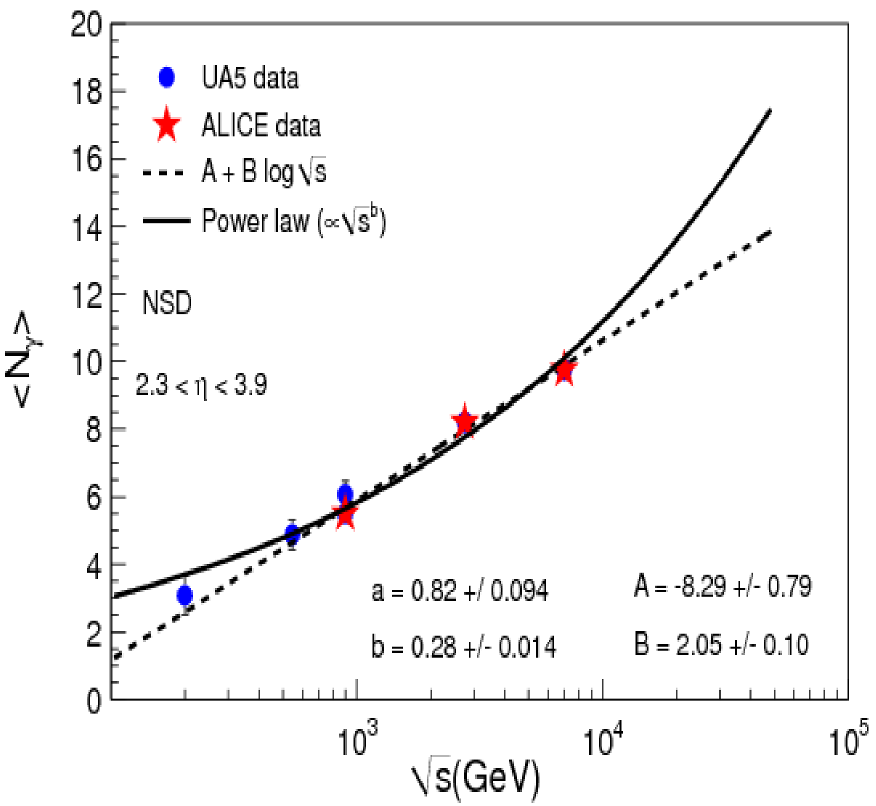
$$\frac{<N_g>^{NSD}}{<N_g>^{INEL}} = 1.20$$

7 TeV

$$\frac{<N_g>^{NSD}}{<N_g>^{INEL}} = 1.18$$

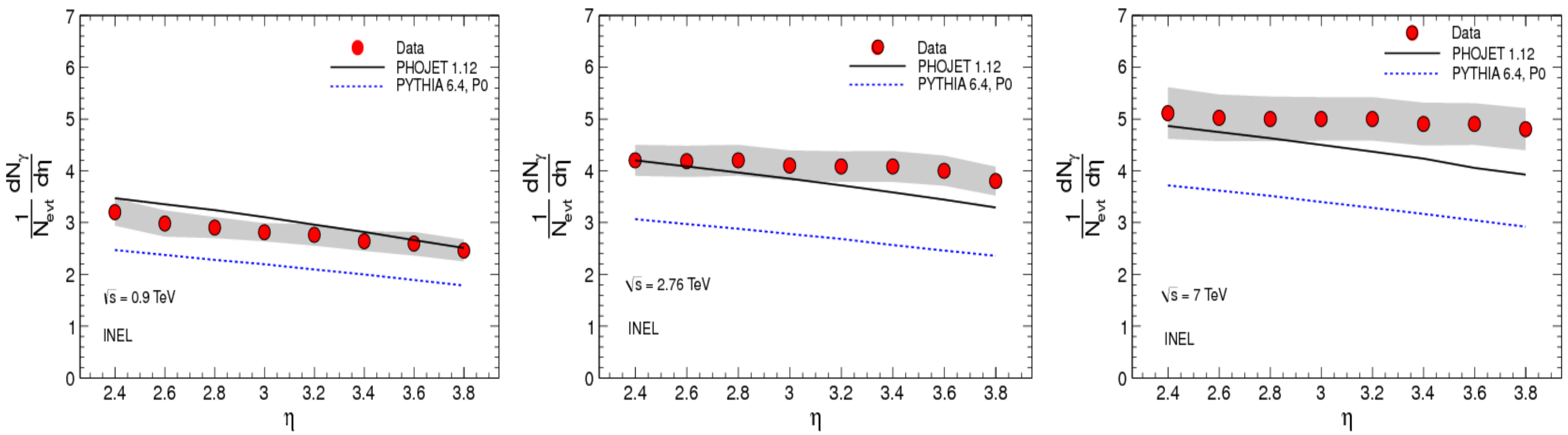
Statistical uncertainties : 0.4%

➢ **Average photon multiplicity in pp collisions (within 2.3<η<3.9) increases with √s as ln√s.**



Pseudo rapidity distribution

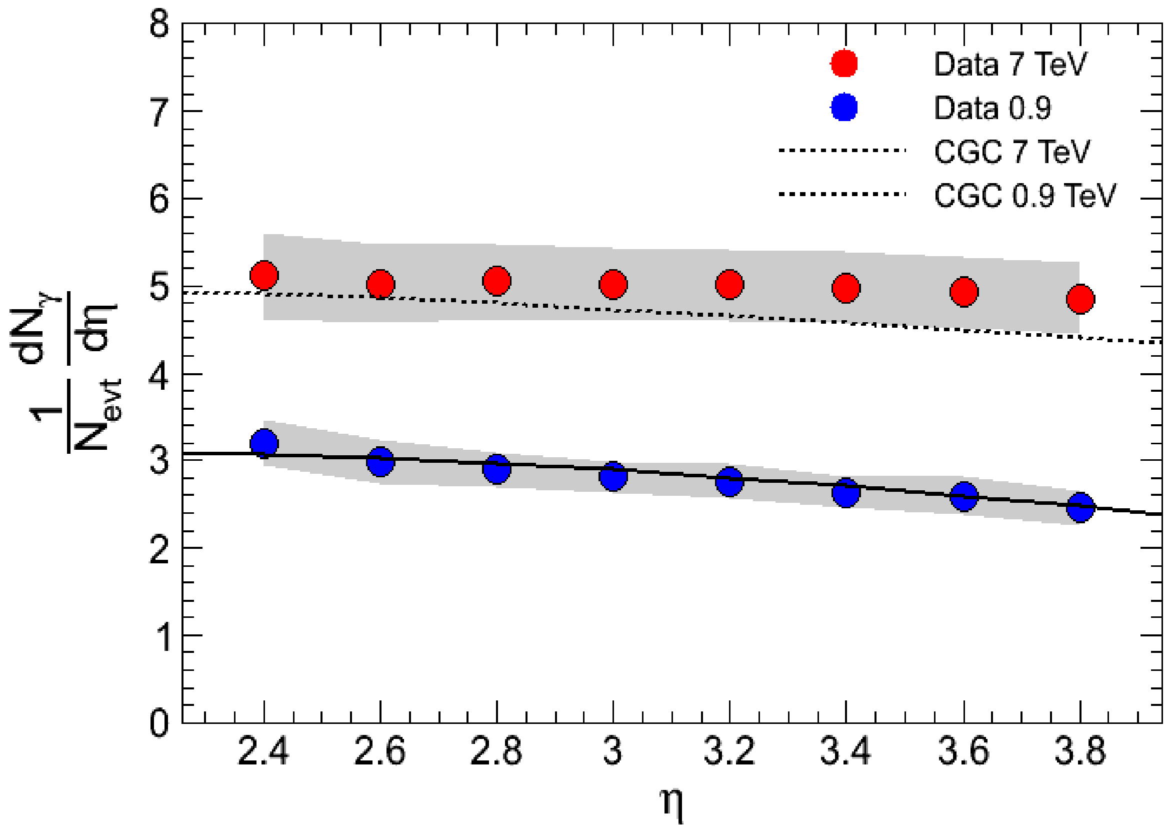
0.9 TeV | 2.76 TeV | 7 TeV



- To get correct $dN_\gamma/d\eta$ unfolding is done in each η bin.

- PHOJET is comparable to the data and PYTHIA under predict the data at 0.9 and 2.76 TeV but at 7 TeV both under predict the data

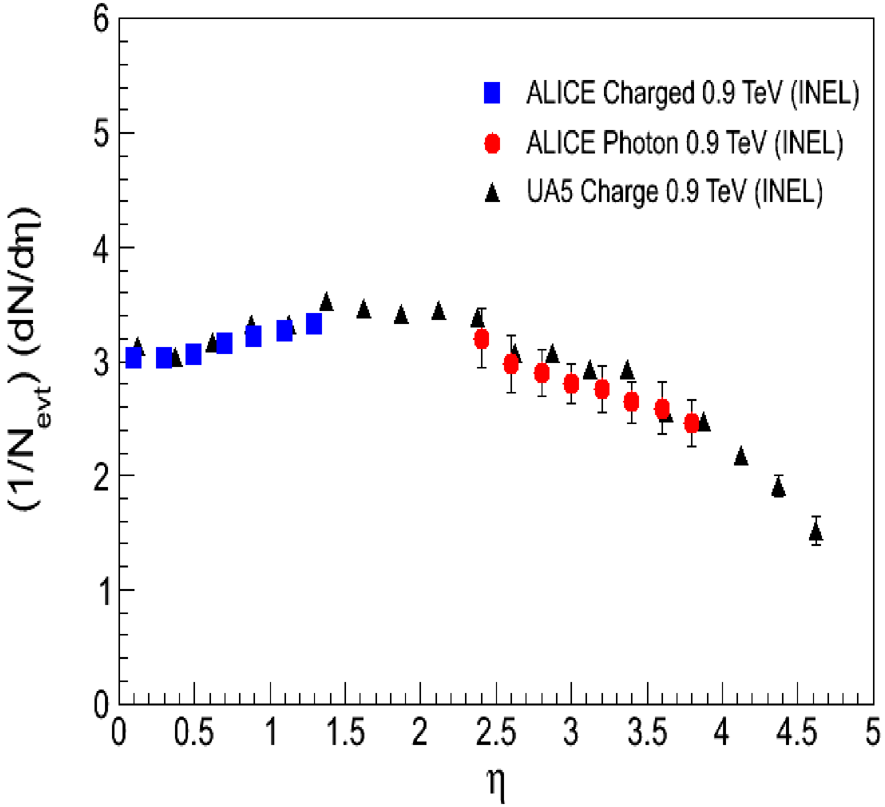
Comparison with CGC model



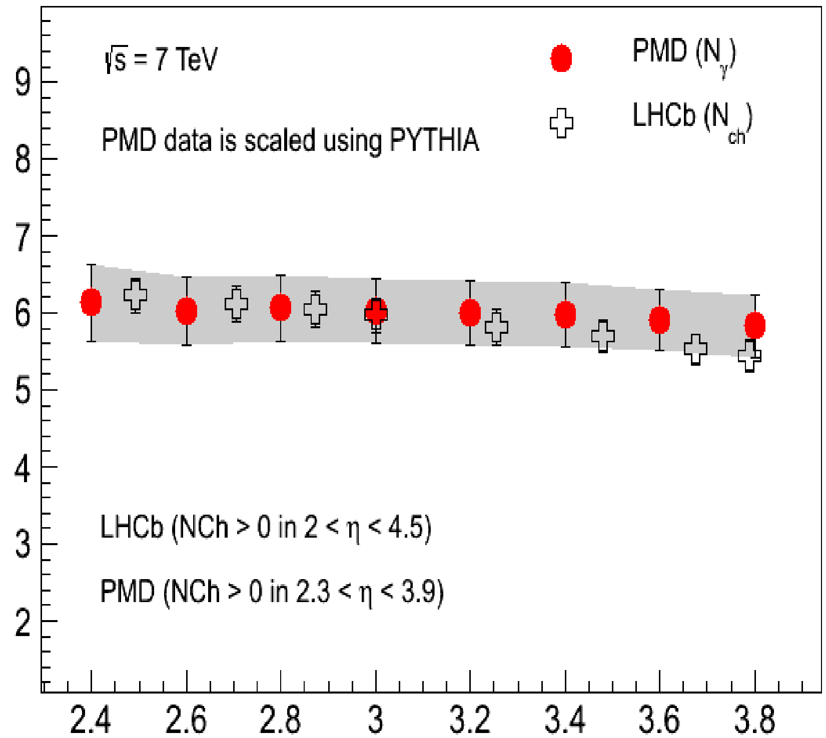
CGC Reference:
Tribedy & Venugopalan ,1011.1895

Comparison with Charged particle production

0.9 TeV

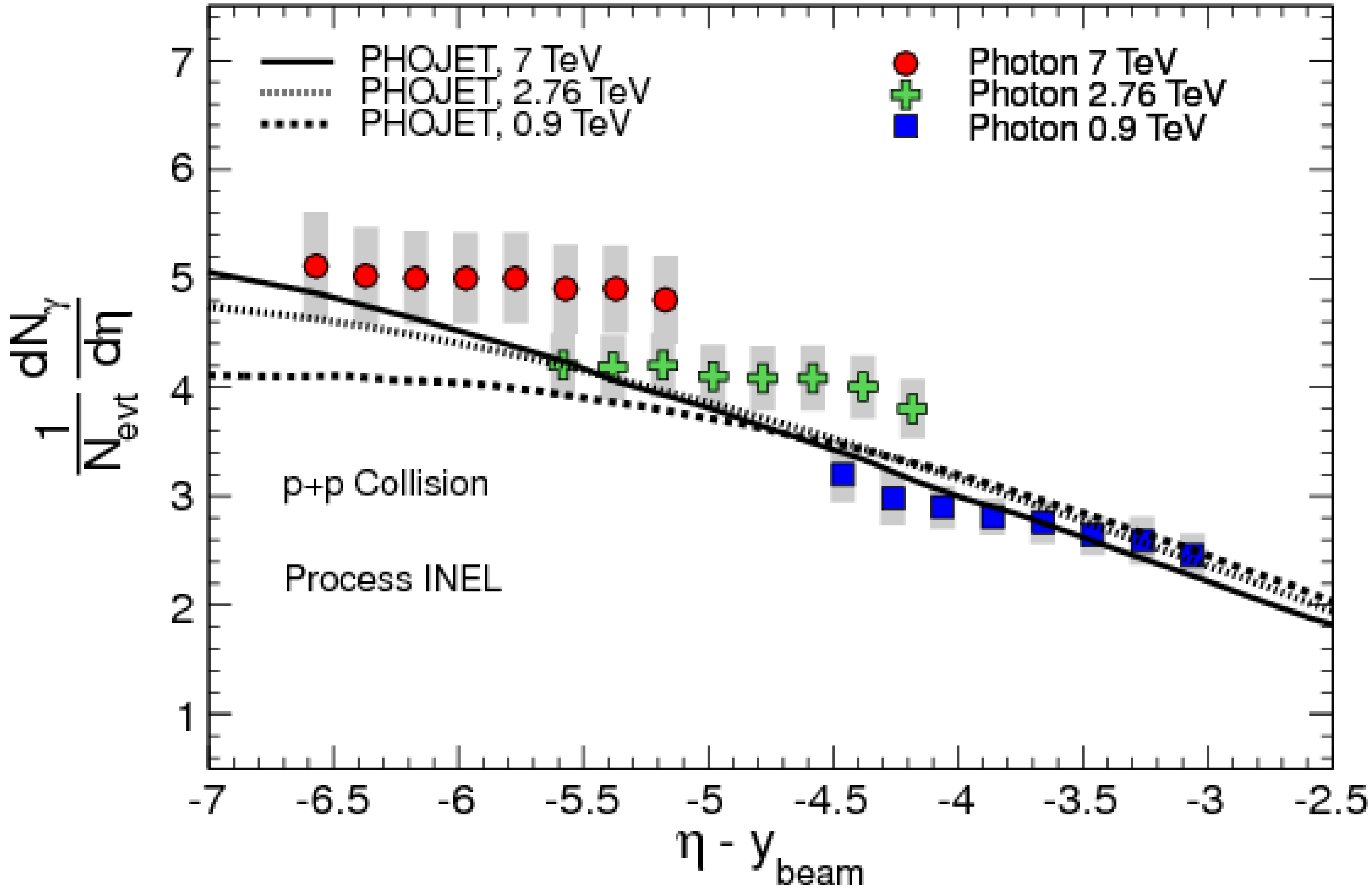


7 TeV

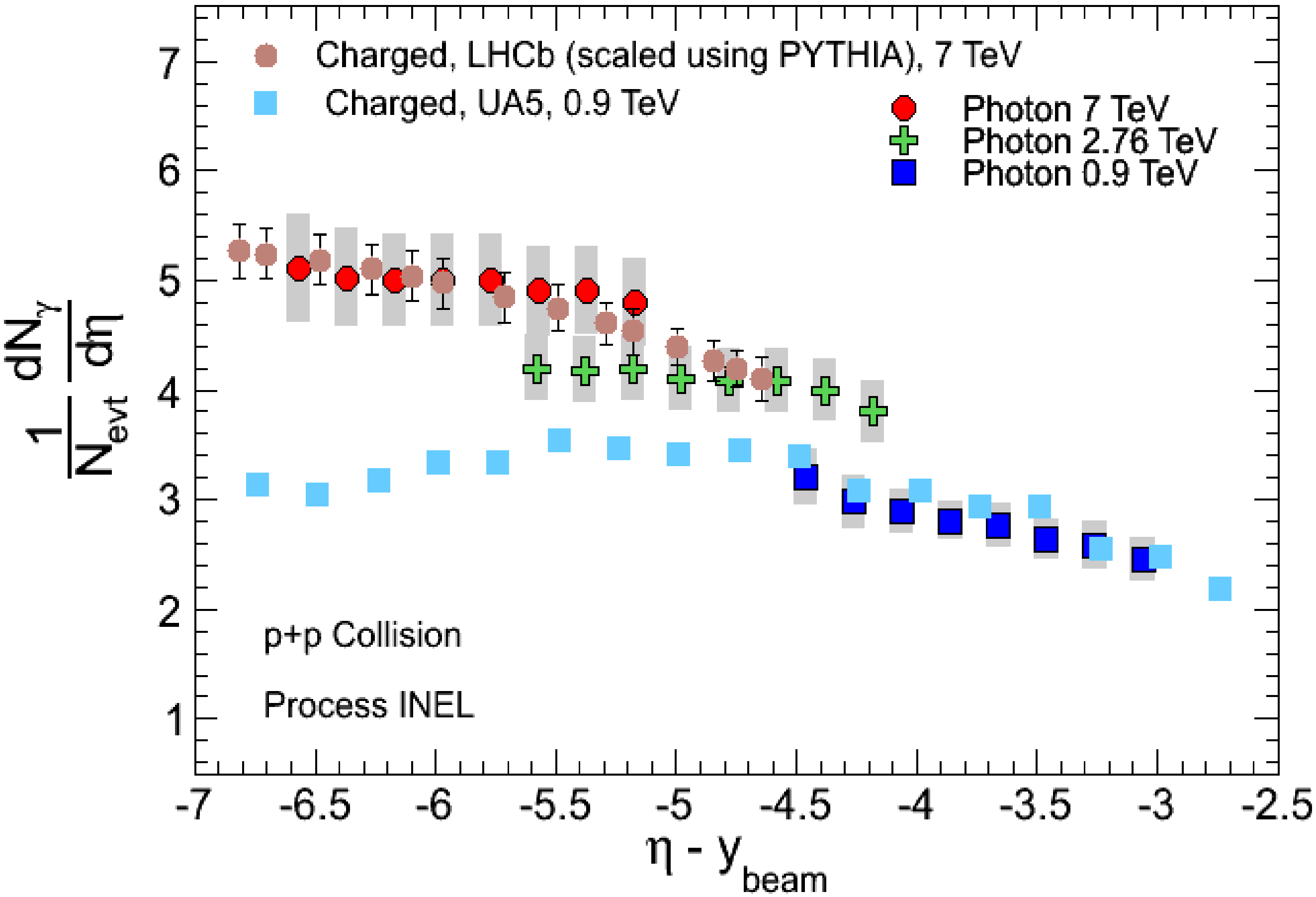


- Inclusive photon production and charged particle production are comparable in forward rapidity region

Limiting fragmentation behavior



Limiting fragmentation behavior



Summary

- Multiplicity and pseudorapidity distribution of photons at forward rapidities are presented in p-p collisions at 0.9, 2.76 and 7 TeV.
- N_γ: for 0.9 and 2.76 TeV PHOJET is closer to data, PYTHIA under-predicts the data. Both models under-predict the data at 7 TeV.
- N_γ distributions are fitted with both single NBD and double NBD functions.
- $\langle N_\gamma \rangle$ grows as $\ln\sqrt{s}$ as well as the power law.
- N_γ production are compared with charged particles production and it is observed that both are comparable in forward rapidity region.
- Limiting fragmentation behavior of N_γ is studied and compared with PHOJET event generators.

Data Taken in p-Pb collisions by PMD

Run Periods:

LHC13b, LHC13c (PMD in proton side) (27M + 89M) (With MB trigger)

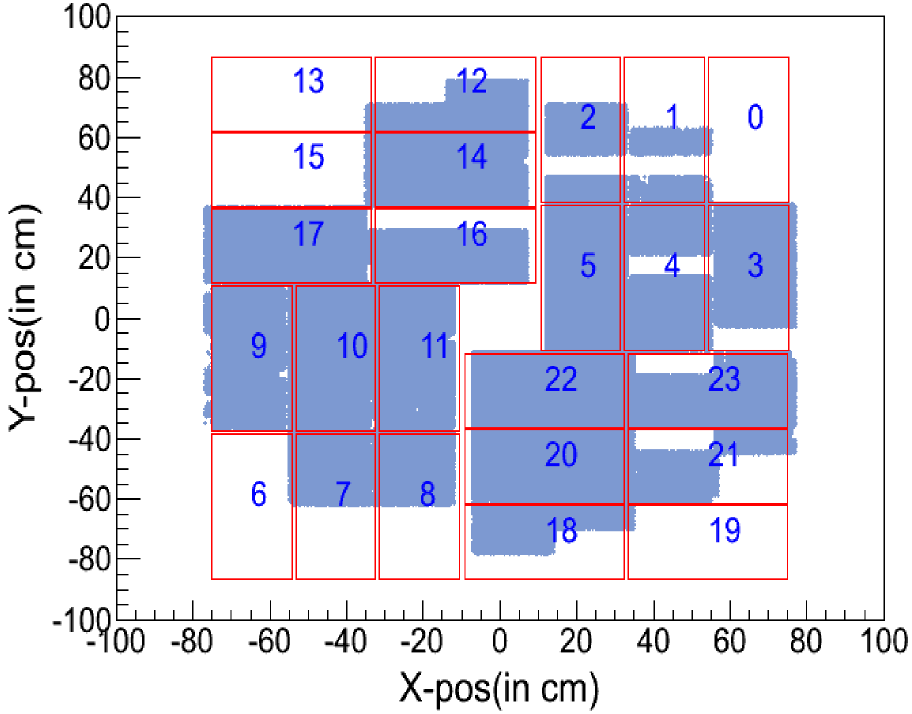
LHC13f (PMD in Pb side) (1.3M with MB trigger and 3M with high rate trigger)

Simulation:
(Data like acceptance is implemented)

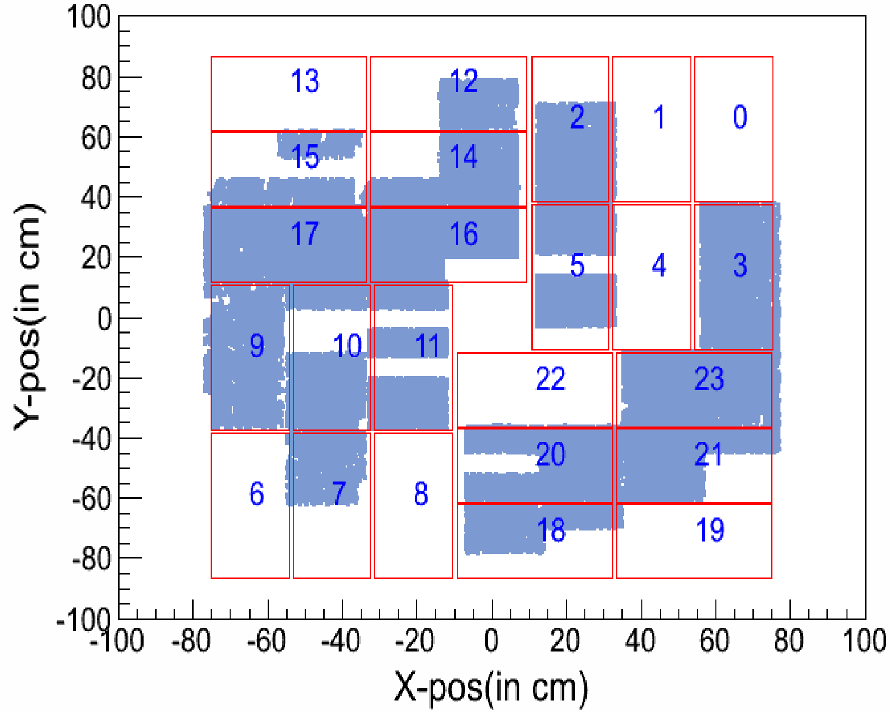
LHC13b_fix_1, LHC13b_fix_2 - DPMJET
LHC13b3 – HIJING

Acceptance of PMD

PRE

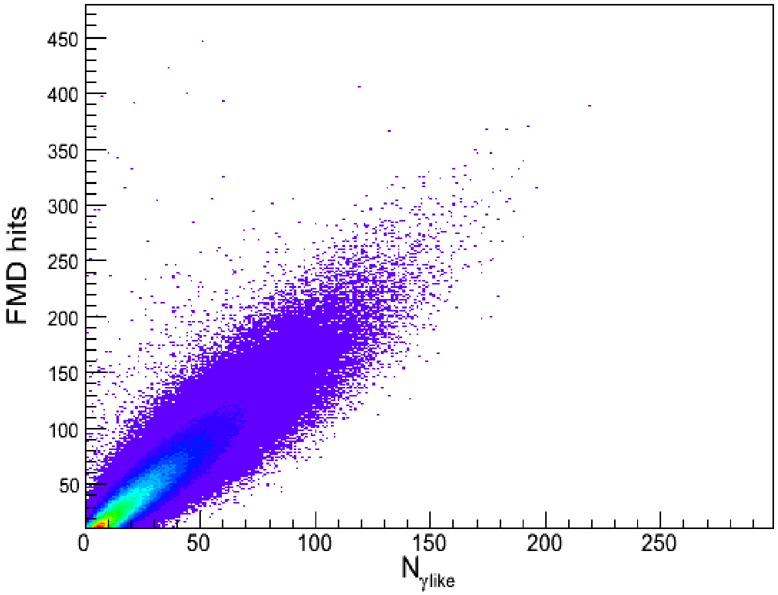


CPV

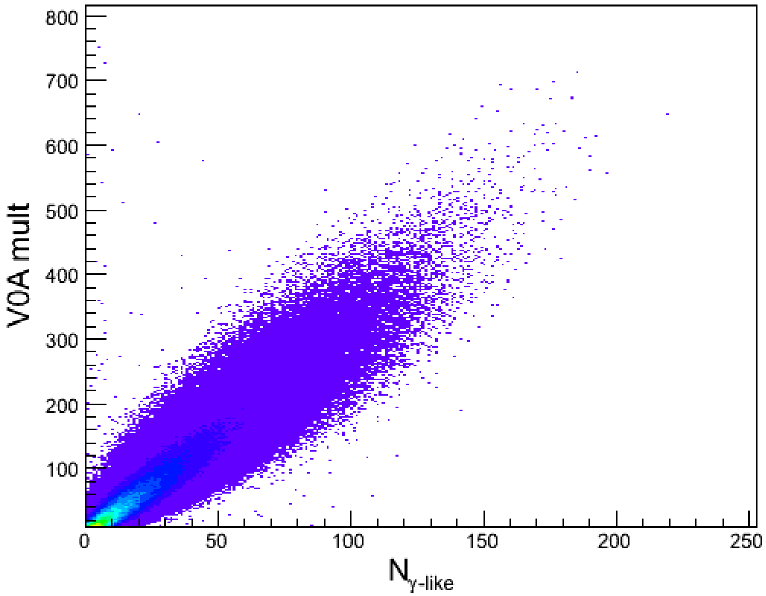


Correlation with FMD and V0A

PMD with FMD



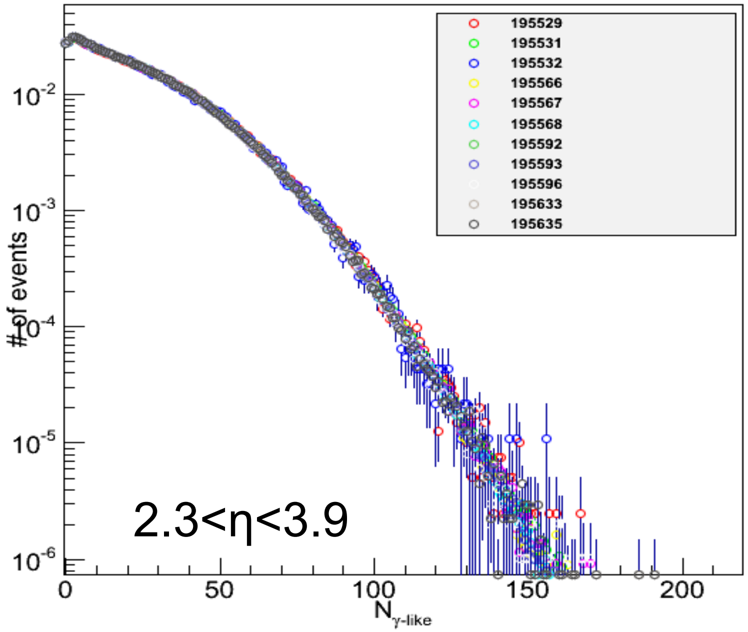
PMD with V0A

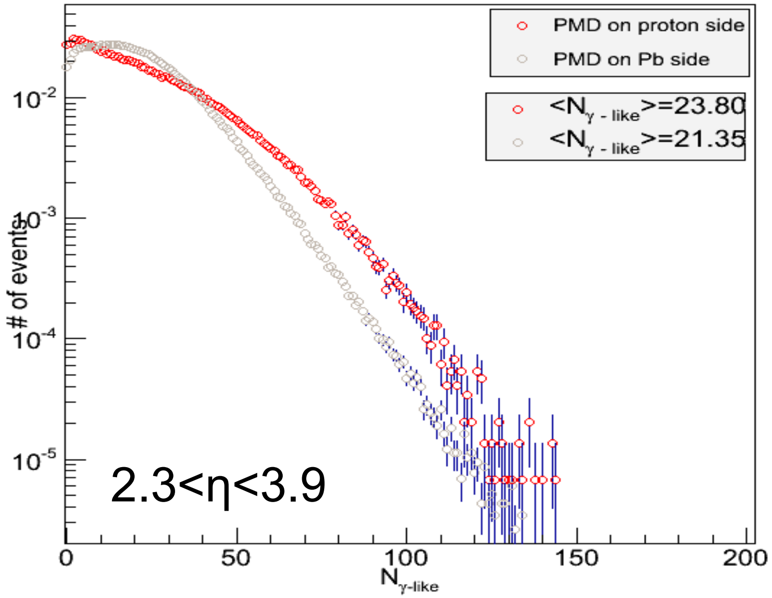


$N_{\gamma like}$ distributions

LHC13b,c (PMD in proton side)

Comparison between different orientation of beams





Analysis details

Run Periods:
LHC13b (~2M event)

Simulation:
LHC13b_fix_1 – DPMJET

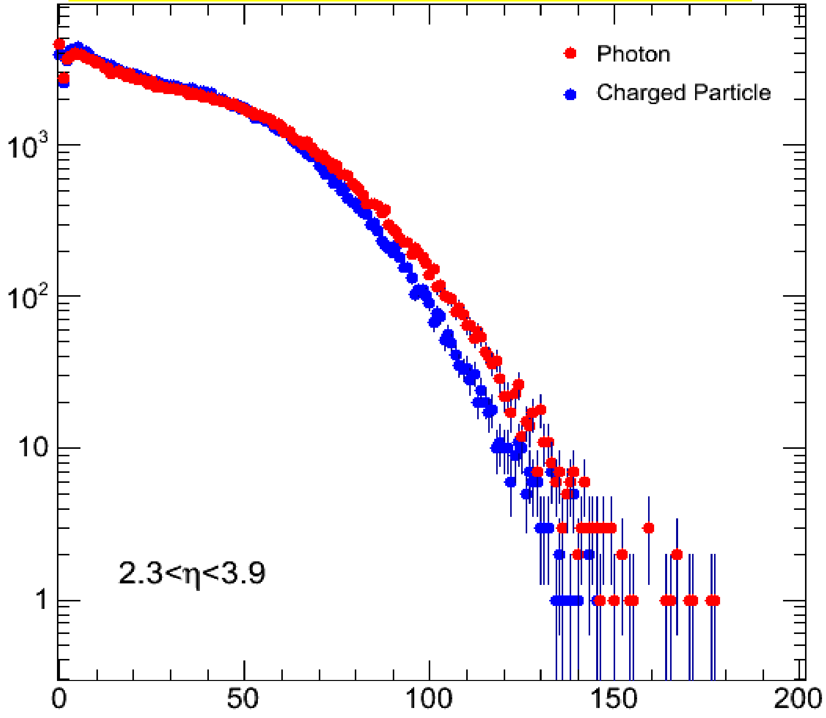
Trigger Class:
kINT7

Vertex cut:
-10< Vz (cm) <10

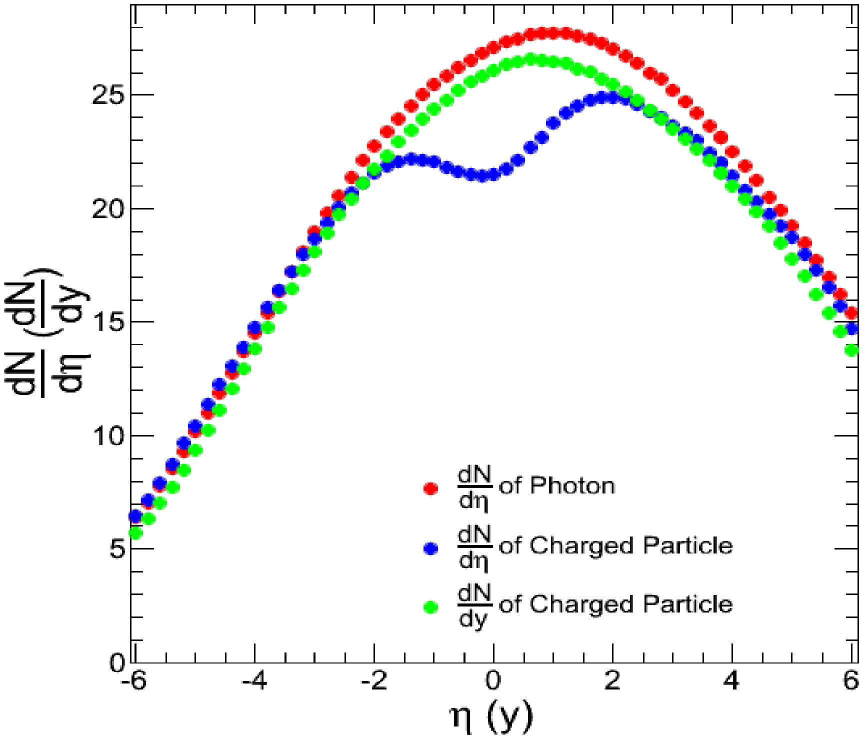
Photon-hadron discrimination cuts:
ADC>432 & ncell >2 and ADC>648 & ncell > 2

Expectation from DPMJET

Multiplicity distribution of photons

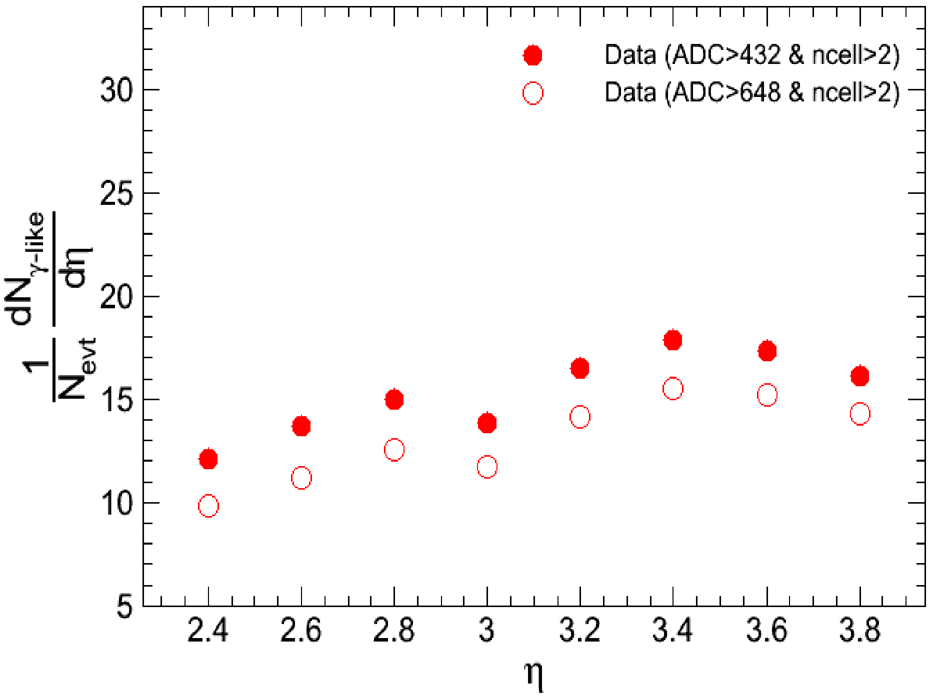


Pseudorapidity distribution of photons



Correction of Data

$N_{\gamma\text{-like}}$ distribution of photons



N_{clus}: the total number of clusters

$N_{\gamma\text{-like}}$: Number clusters above thresholds on number of cells and Cluster ADC.

$N_{\gamma\text{-det}}$: Number of photons detected above the threshold

$N_{\gamma\text{-true}}$: Number of photons incident

purity = $\mathbf{N_{\gamma\text{-det}} / N_{\gamma\text{-like}}}$

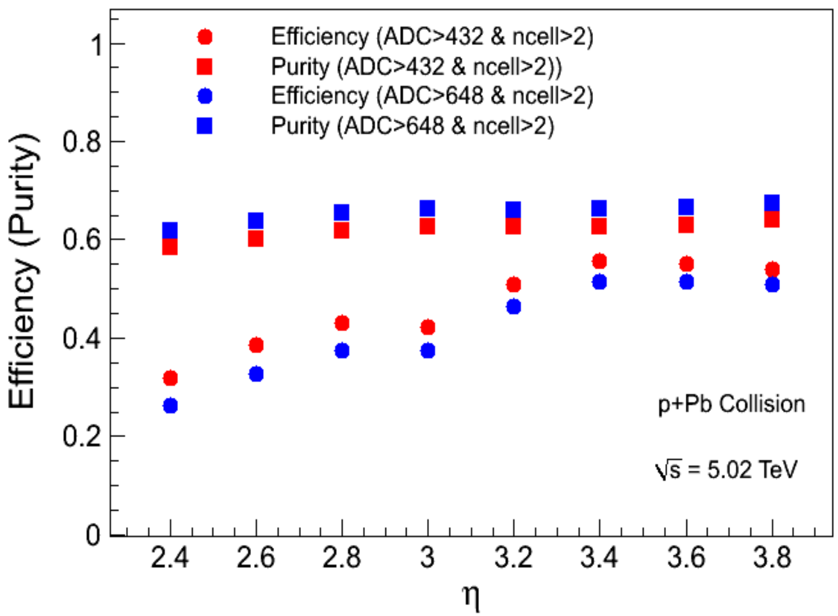
Efficiency = $\mathbf{N_{\gamma\text{-det}} / N_{\gamma\text{-true}}}$

From the experiment we have $N_{\gamma\text{-like}}$ which is corrected using simulation and we get

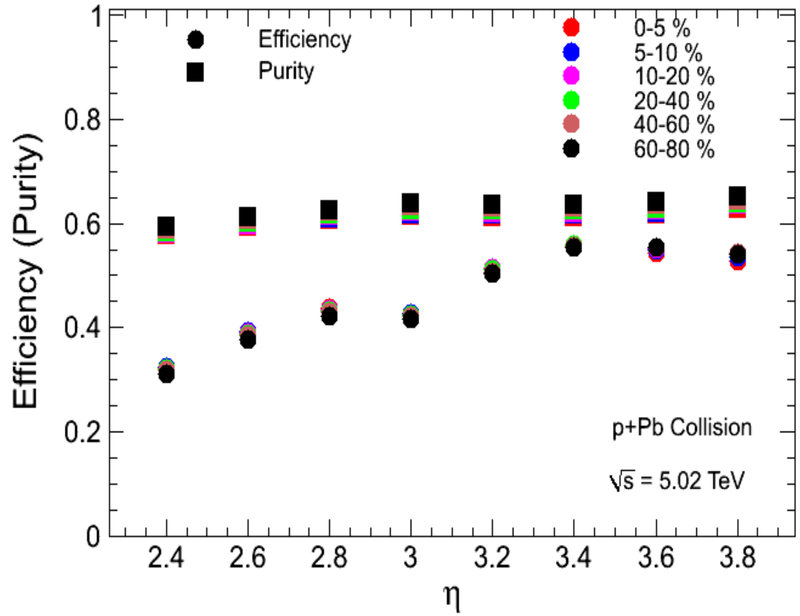
$$\mathbf{N_{\gamma} = N_{\gamma\text{-like}}(data) \times (purity/Efficiency)}$$

Efficiency Purity

Minimum bias

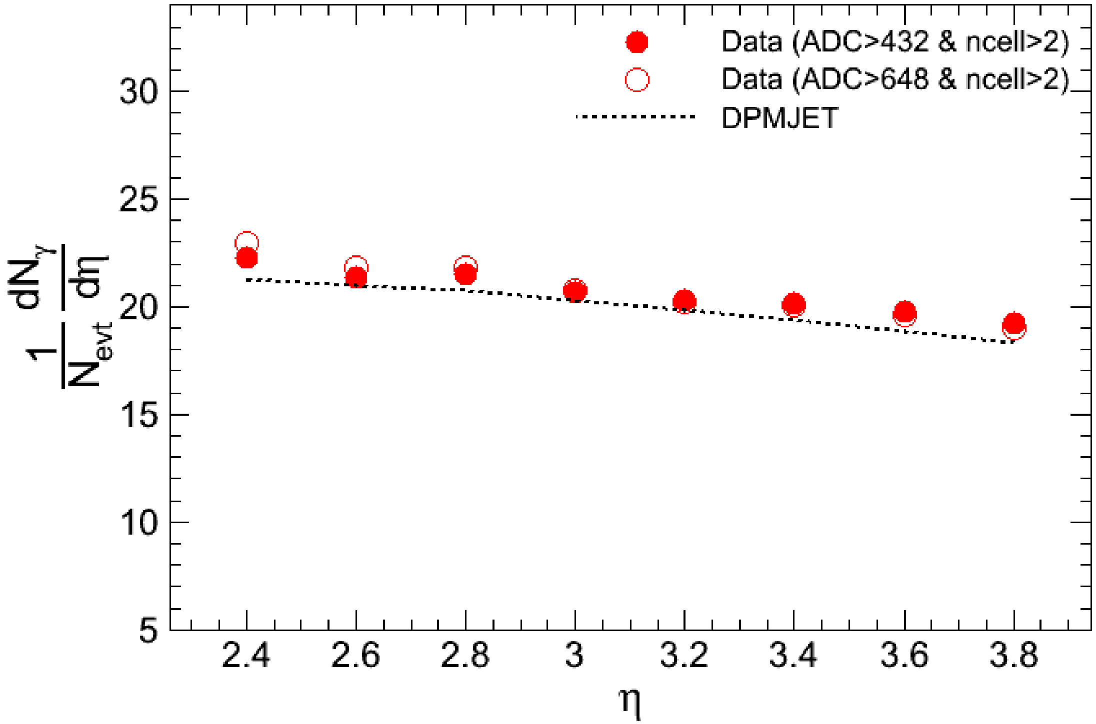


Different centrality classes



- Acceptance is folded in the efficiency and purity
- Efficiency and purity are centrality independent.

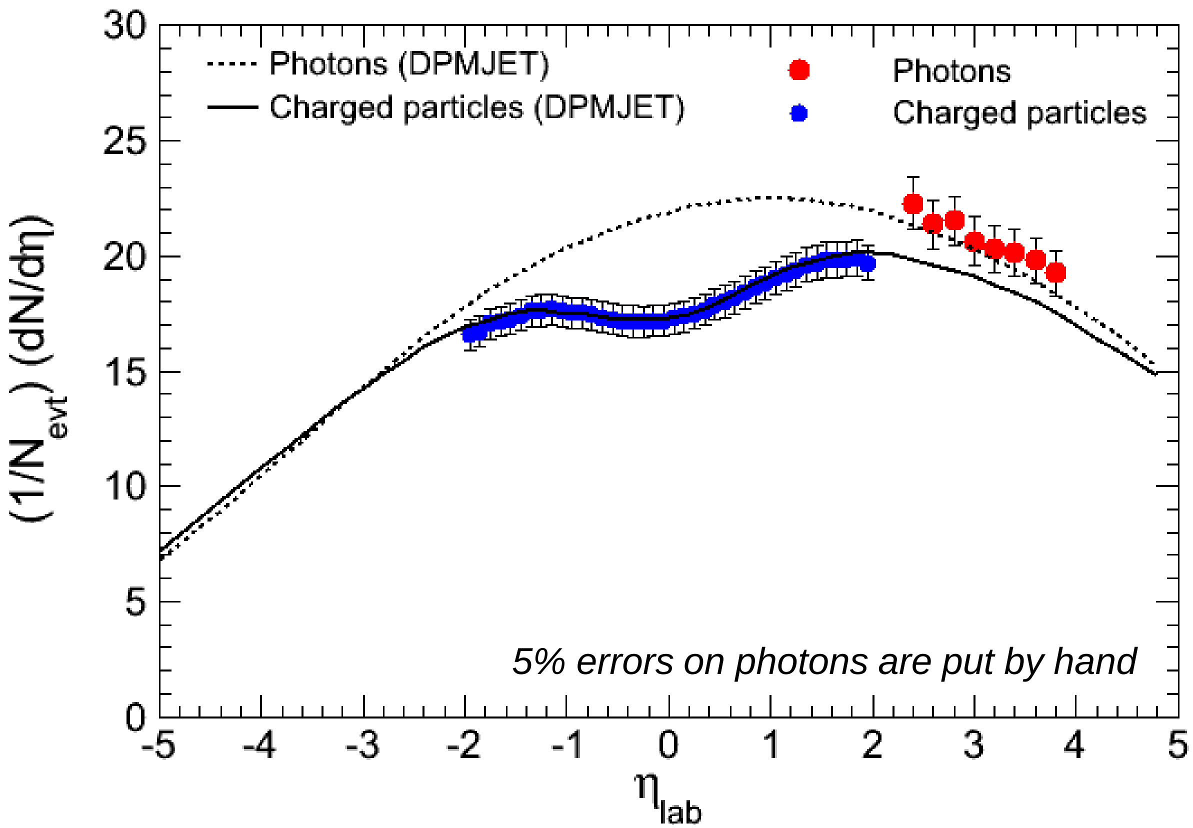
Corrected pseudorapidity distribution of photons



- After correction the results are comparable for two different thresholds which shows the robustness of the results.

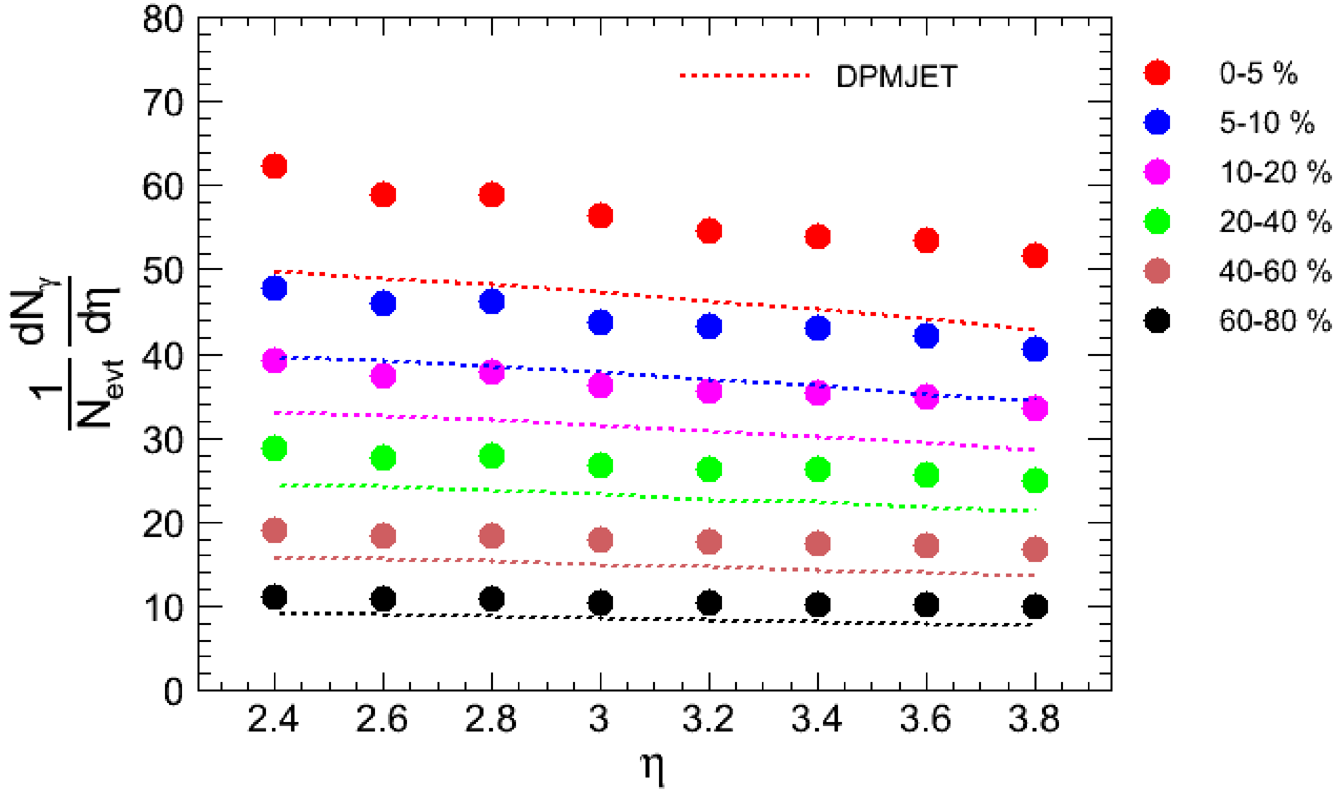
- DPMJET is closer the data.

Comparison with charged particle production



- Results are compared to charged particle production in central rapidity (-2<η<2) region. and it is found that photon production is seems to be higher than that of charged particles productions
- Similar behavior is found in DPMJET also.

In different centrality classes



➢Results are presented in different centrality classes. Photon production is highest in top (0-5%) centrality class and decreases along more more peripheral collisions.

Summary

- Psedorapidity distribution of photons are presented within 2.3 < η < 3.9 at 5.02 TeV p-Pb collisions

- Results are compared with the model DPMJET and it is shown that the DPMJET is closer to data.

- Results are compared to charged particle production in central rapidity (-2<η<2) region. and it is found that photon production is seems to be higher than that of charged particles productions

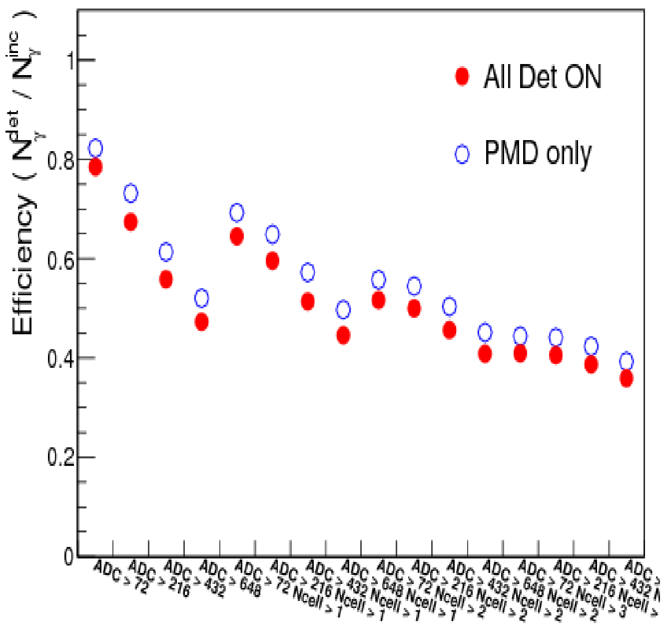
- Results are presented in different centrality classes. Photon production is highest in top (0-5%) centrality class and decreases along more more peripheral collisions.

To do:

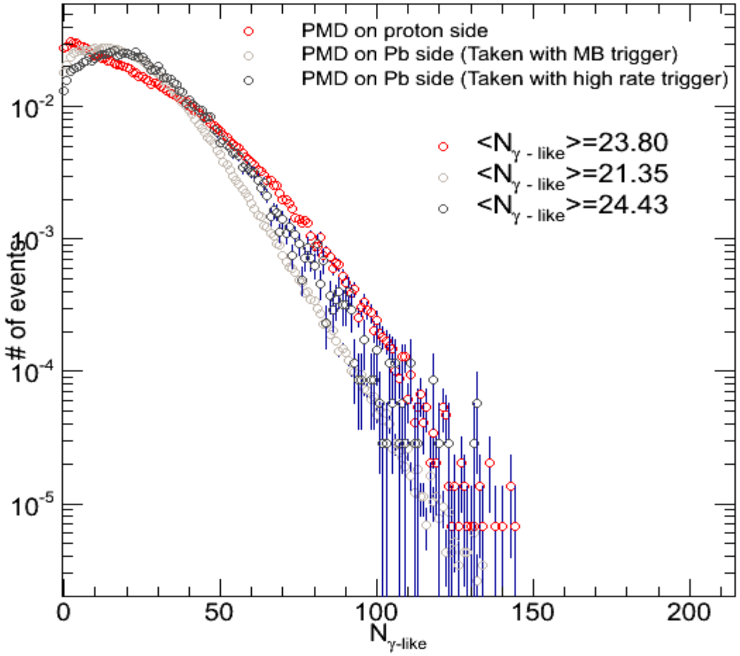
- Increasing the statistics
- Try unfolding method to correct the data
- Use another event generator (HIJING) to correct the data
- All systematic errors studies which have been done in pp collisions

Back Up

Back Up


Efficiency (N_γ^{det} / N_γ^{inc})
1
0.8
0.6
0.4
0.2
0
All Det ON
PMD only

Back Up



PMD on proton side
PMD on Pb side (Taken with MB trigger)
PMD on Pb side (Taken with high rate trigger)
<N_γ - like>=23.80
<N_γ - like>=21.35
<N_γ - like>=24.43
# of events
N_γ-like
0
50
100
150
200