Study of neutral mesons in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV in the ALICE experiment at LHC

Hot Quarks Workshop

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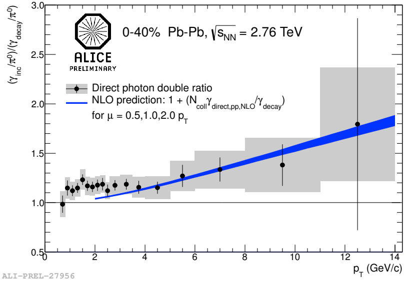
Motivations

In heavy-ion collisions, π^0 and η measurements are used:

✦ to obtain nuclear modification factor R_{AA} and study nuclear effects

✦ to study the energy loss via particle suppression

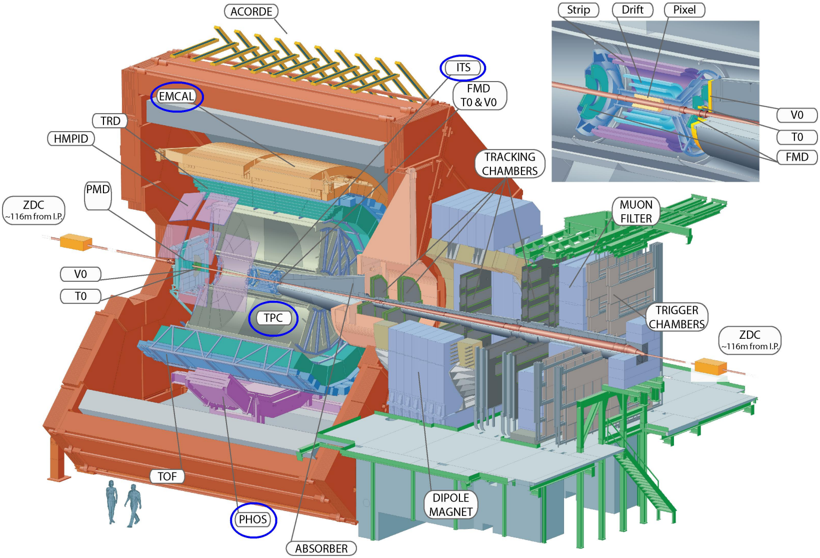
✦ π^0 and η needed as input for direct-photon (and electron from heavy-flavour) measurement as they represent the largest source of decay photons (98%)



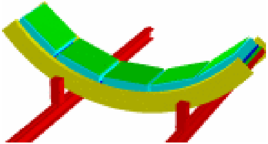
π^0 and η meson

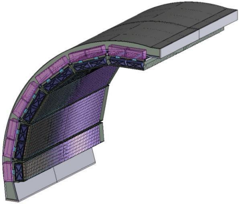
	$\pi^0 = \frac{1}{\sqrt{2}}[\vert u\bar{u}\rangle - \vert d\bar{d}\rangle]$	$\eta = \frac{1}{\sqrt{6}}[\vert u\bar{u}\rangle - \vert d\bar{d}\rangle - 2\vert s\bar{s}\rangle]$
Mass	$0.135\ \mathrm{GeV}/c^2$	$0.548\ \mathrm{GeV}/c^2$
Decay	$\pi^0 \rightarrow \gamma\gamma \rightarrow e^+e^-e^+e^-$	$\eta \rightarrow \gamma\gamma \rightarrow e^+e^-e^+e^-$
B.R.	98%	39%

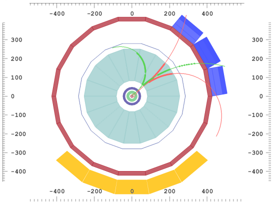
The ALICE experiment



Photon detection with the ALICE experiment

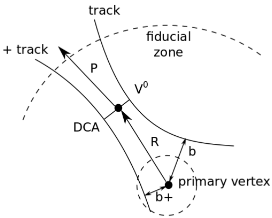


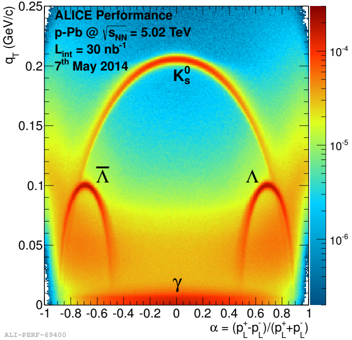




- ✦ PHOS calorimeter:
  - → $PbWO_4$ crystal
  - → 3 modules at 4.6 m from IP
  - → $|\eta| < 0.13$, $260° < \phi < 320°$
- ✦ EMCal calorimeter:
  - → 77 layers, 1.4 mm Pb and 1.7 mm scintillator
  - → 10 modules at 4.4 m from IP
  - → $|\eta| < 0.7$, $80° < \phi < 180°$
- ✦ Photon Conversion Method (PCM):
  - → conversion in detector material
  - → ITS and TPC ($X/X_0 = 11.4 \pm 0.5_{sys}\%$)
  - → $|\eta| < 0.9$, $0° < \phi < 360°$

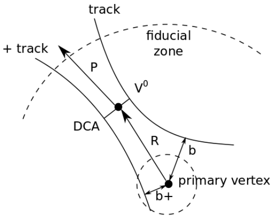
The Photon Conversion Method

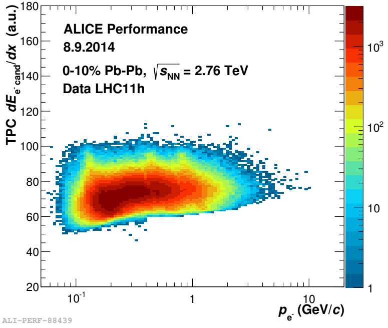




- Based on the reconstruction of photon conversions in the detector material by **ITS** and **TPC**
- Secondary vertex finder used to identify the conversion point: two oppositely charged secondary tracks selected considering their DCA < 1 cm
- Secondary vertexes found are kept if:
  - → they lie inside of a fiducial zone
  - → the momentum vector of **secondary vertex V^0** (P) points to the primary vertex
  - → reconstructed tracks pass standard quality cuts
- Cut on R, minimum $p_{\mathrm{T,\,track}}$, minimum fraction of TPC clusters to findable clusters, TPC nσ dE/dx for e^- and π

The Photon Conversion Method





- Based on the reconstruction of photon conversions in the detector material by ITS and TPC
- Secondary vertex finder used to identify the conversion point: two oppositely charged secondary tracks selected considering their DCA < 1 cm
- After electron selection, additional cuts specific for photons are applied to increase sample purity
  - → cut on χ^2/ndf of reconstructed photons
  - → elliptic cut on Armenteros-Podolansky plot
  - → cut on the ψ_{pair} angle (opening angle perpendicular to B field)
  - → cosine of pointing angle

Data sets and MC simulations for collisions at 2.76 TeV

pp	Energy	N_{events}
Data	$\sqrt{s}$ **= 2.76 TeV** (2011)	5.74e+07
MC	Pythia 6 (tune Perugia 0)	1.63e+06
	Pythia 8	3.14e+07
	Pythia 8 (Add GA sig.)	1.10e+07
	Phojet	2.92e+07

Pb-Pb	Energy	Centrality	N_{events}
Data	$\sqrt{s_{NN}}$ **= 2.76 TeV**	0- 5%	8.43e+05
	(2010)	5-10%	8.44e+05
		10-20%	1.68e+06
		20-40%	3.37e+06
		40-60%	3.37e+06
		60-80%	3.37e+06
MC	$\sqrt{s_{NN}} = 2.76$ TeV	0- 5%	2.61e+05
	(Hijing)	5-10%	2.82e+05
	Minimum Bias	10-20%	6.28e+05
		20-40%	6.28e+05
		40-60%	1.73e+06
		60-80%	2.43e+06
		20-40%	7.46e+05
	Minimum Bias	40-60%	8.76e+05
	+ *flat* p_T π^0, η	60-80%	1.24e+06
Data	$\sqrt{s_{NN}}$ **= 2.76 TeV**	0-10%	1.9e+07
	(2011)	20-50%	1.3e+07
MC	$\sqrt{s_{NN}} = 2.76$ TeV	0-10%	1.4e+06
	(Hijing)	20-50%	2.9e+06
	+ *flat* p_T π^0, η		

Invariant mass reconstruction

Photon candidates extracted from the V^0s (secondary vertex particles) sample **are combined into pairs** for which the invariant mass is calculated, in p_{T} slices, according to transverse momentum binning of final meson spectra:

$$M_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{12})}$$

The background is calculated with the Event Mixing (EM) technique and normalized to the combined signal and background distribution

After the background subtraction, the distribution is fitted with:

$$y = A\cdot\left(G(M_{\gamma\gamma}) + \exp\left(\frac{M_{\gamma\gamma}-M_{\pi^0(\eta)}}{\lambda}\right)(1-G(M_{\gamma\gamma}))\theta(M_{\pi^0(\eta)}-M_{\gamma\gamma})\right) + B + C\cdot M_{\gamma\gamma}$$

$$\text{where}\quad \mathrm{G} = \exp\left(-0.5\left(\frac{M_{\gamma\gamma}-M_{\pi^0(\eta)}}{\sigma_{M_{\gamma\gamma}}}\right)^2\right)$$

Signal extraction

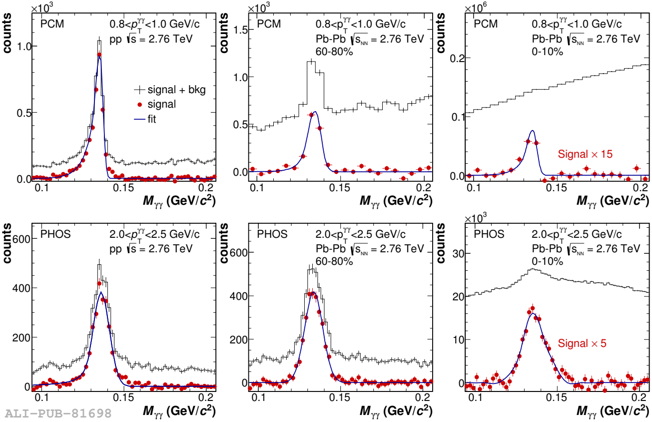
- **PHOS:**
  - → adjacent cells with energy signals above a 12 MeV grouped into clusters then summed up to determine the photon energy
  - → fit with Gaussian or a Crystal Ball function and linear fit to account for combinatorial background under the peak
- **EMCal:**
  - → clusterizer searches for towers with energy above seed energy and adds all surrounding towers with energy higher than threshold; procedure stopped if neighboring tower energy is higher
  - → fit with a combined π^0 and η Crystal-Ball and a parabola for the background hypothesis
- **PCM:** fit using Gaussian function combined with exponential tail on left side of the peak (due to electron bremsstrahlung) and with linear fit to account for combinatorial background under the peak

π^0 signal extraction

π^0 obtained from PCM and PHOS measurement [arXiv:1405.3794v1]

PCM

PHOS



Black histogram: signal and background distribution

Red points: signal after background subtraction

Blue line: fit to the signal

π^0 signal extraction

To extract the signal

- **subtracted invariant mass distribution is integrated**
  - → PHOS: $\pm\, 3\sigma$ around mean value of π^0 peak
  - → PCM: in a mass range around the fitted meson mass in an asymmetric window in order to include electron bremsstrahlung tail (m_{π^0} - 0.035 GeV/c^2, $m_{\pi^0} + 0.010$ GeV/c^2)
- **residual background is subtracted** using the integral of the linear fit

Efficiency and acceptance obtained through Monte Carlo simulations

→ PHOS: acceptance is zero for $p_T < 0.6$ GeV/c

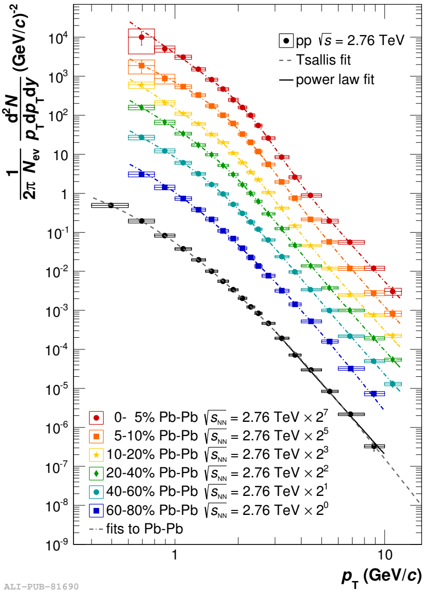
→ PCM: efficiency is dominated by conversion probability

π^0 corrected yield

- Invariant differential π^0 yield:

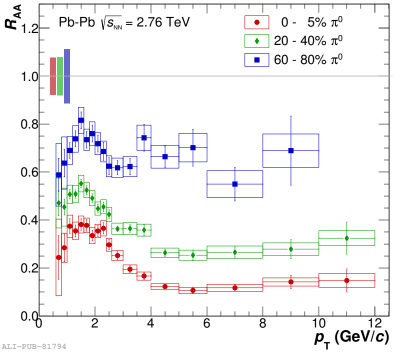
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{1}{N_{\text{events}}}\frac{1}{p_T}\frac{1}{\epsilon A}\frac{1}{\text{B.R.}}\frac{N^{\pi^0}}{\Delta y \Delta p_T}$$

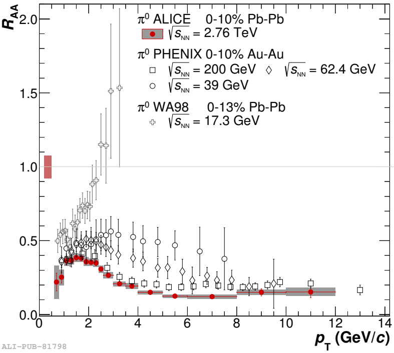
- Combined PHOS and PCM spectra obtained as a weighted average of the individual results [arXiv:1405.3794v1]
- The relevant systematic errors are yield extraction for PHOS and material budget for PCM



π^0 R_{AA}

R_{AA} was calculated as a weighted average of individual measurements with PHOS and PCM $\Rightarrow$ reduced systematic uncertainties





$\Rightarrow$ decrease of R_{AA} due to higher initial energy densities at larger $\sqrt{s_{NN}}$ dominates over increase due to harder initial parton p_T spectra

Conclusions on results with 2010 Pb-Pb collisions data

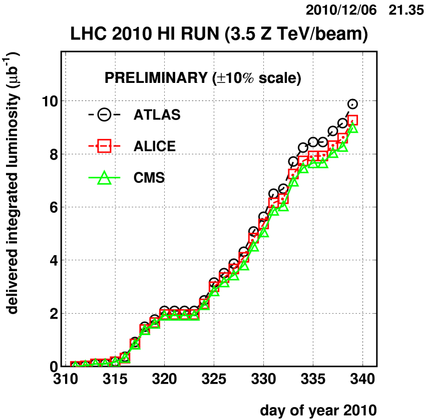
From the results obtained analysing the data on Pb-Pb collisions from 2010 it can be concluded:

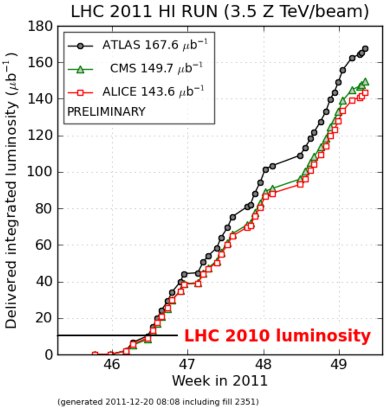
- the two independent measurements with PCM and PHOS give consistent results
- π^0 suppression in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV stronger than in Au-Au collisions at $\sqrt{s_{NN}}$=200 GeV at RHIC for all centralities

The η meson, interesting by itself, is also key measurement:

- compare η R_{AA} to π^0 R_{AA} and to η R_{AA} from RHIC results
- η contribution needed to improve cocktail used to calculate the decay photons (only π^0 in the cocktail now, m_T-scaling is used to estimate contribution from the unmeasured mesons)
- η meson not measured before in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV at the LHC because statistics from Pb-Pb collisions collected in 2010 not sufficient for a significant measurement

Luminosity 2010 vs 2011





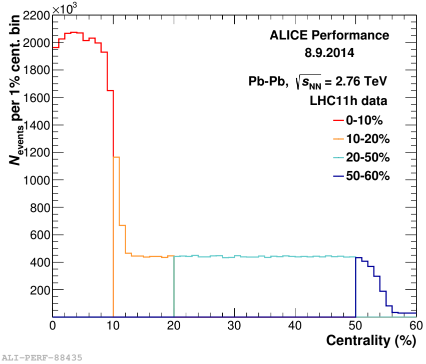
⇒ with large statistics collected in 2011 measurement of differential invariant cross section is possible

π^0 and η in 2011 data

With larger statistics available

- π^0 p_T range can be extended up to 14 GeV/c with PCM only
- η p_T range:

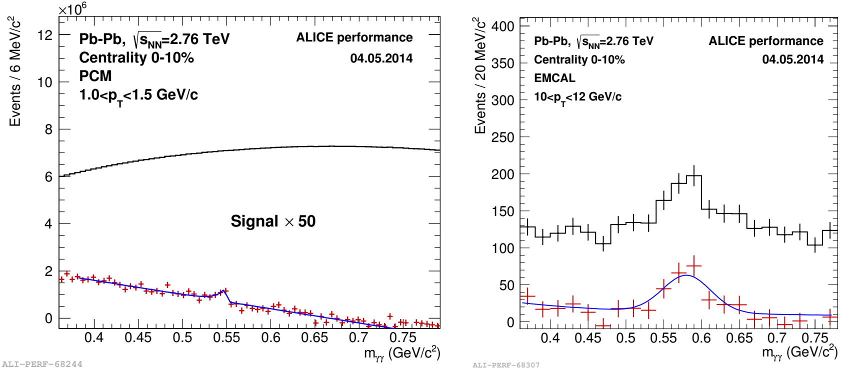
	p_T (GeV/c)
PCM	1 GeV/c – 10 GeV/c
EMCal	5.5 GeV/c – 22 GeV/c
Combined	1 GeV/c – 22 GeV/c



- centrality trigger used: combination of triggers for central and semicentral events and minimum bias events (kCentral+kSemiCentral+kMB)

η signal extraction

! $\Rightarrow$ lowest p_T bin for PCM: higher background, lower statistics



Black histogram: signal and background distribution
Red points: signal after background subtraction
Blue line: fit to the signal and residual background distribution

Conclusions

- ✔ The two independent measurements with PCM and PHOS give consistent results
- ✔ Comparison with theoretical models (GLV calculations, WHDG model, EPOS, Nemchick *et al.* calculation)
- ✔ π^0 suppression in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV stronger than in Au-Au collisions at $\sqrt{s_{NN}}$=200 GeV at RHIC for all centralities
- ✔ π^0 p_{T} range can be extended up to 14 GeV/c with data from 2011 Pb-Pb collisions
- ✔ η measurable with data from 2011 Pb-Pb collisions with good significance
- ✔ η combined measurement from PCM and EMCal should range from $p_{\mathrm{T}} = 1$ GeV/c up to 22 GeV/c

Conclusions

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Thank you for the attention!

Back up

Analysis cuts - 2010 data

Conversion cuts

V0-finder	On-the-Fly
η cut	$\lvert\eta\rvert < 0.65$
R cut	5 cm $< R_{conv} <$ 180 cm
minimum track p_{T}	$p_{\mathrm{T,\ track}} > 0.05$ GeV/c
$\frac{N_{clsTPC}}{N_{findablecls}}$	$> 60\%$
nσ_e TPC dE/dx	-3 $< n\sigma_e <$ 5
nσ_π TPC dE/dx	$n\sigma_\pi > 3$ (0.4 GeV/$c < p <$ 100 GeV/c)
nσ_e TOF dE/dx	-5 $< n\sigma_e <$ 5
q_{T} cut	< 0.05 GeV/c
χ^2/ndf	< 20
ψ_{pair} cut	< 0.05

Meson cuts

y cut	$\lvert y\rvert < 0.6$
α cut	< 0.65 (central) (where $\alpha = \lvert\frac{E_{\gamma_1} - E_{\gamma_2}}{E_{\gamma_1} + E_{\gamma_2}}\rvert$)
	< 0.8 (peripheral)

Analysis cuts - 2011 data

Conversion cuts

V0-finder	On-the-Fly
η cut	$\|\eta\| < 0.9$
R cut	5 cm $< R_{conv} <$ 180 cm
minimum track p_{T}	$p_{T,track} > 0.05$ GeV$/c$
$\frac{N_{clsTPC}}{N_{findablecls}}$	$> 60\%$
nσ_e TPC dE/dx	-3 $< n\sigma_e <$ 5
nσ_π TPC dE/dx	$n\sigma_\pi > 3$ (0.4 GeV$/c < p <$ 100 GeV$/c$)
nσ_e TOF dE/dx	-5 $< n\sigma_e <$ 5
q_T cut	< 0.05 GeV$/c$ (2D cut, $(\frac{\alpha}{0.95})^2 + (\frac{q_T}{q_{T,max}})^2 > 1$)
$\chi^2/$ndf	< 30
ψ_{pair} cut	< 0.1 (2D cut, $\|\psi_{pair}\| < \frac{-\psi_{pair,max}}{\chi^2_{\gamma,max} \cdot \chi^2 + \psi_{pair,max}}$)
$\cos(P.A.)$ cut	> 0.85

Meson cuts

y cut	$\|y\| < 0.85$
α cut	< 0.8 (where $\alpha = \|\frac{E_{\gamma_1} - E_{\gamma_2}}{E_{\gamma_1} + E_{\gamma_2}}\|$)

η signal extraction in Pb-Pb 2011

To extract the signal

- ✦ EMCal:
  - → fit with a **Crystal-Ball function**
  - → fit of background assumed as a **straight line combined with a power law**
- ✦ PCM:
  - → **subtracted invariant mass distribution is integrated** in a mass range around the fitted meson mass in an asymmetric window in order to include bremsstrahlung tail

    $(m_\eta - 0.047 \text{ GeV}/c^2, m_\eta + 0.023 \text{ GeV}/c^2)$
  - → **residual background is subtracted** using the integral of the linear fit

PCM corrections

The raw yields are corrected for **detector acceptance** and **reconstruction efficiency**

- geometrical acceptance:

$$A_\eta = \frac{N_{\eta,|y|<y_{\mathrm{max}}} \text{ with daughters within } |\eta_\gamma| < 0.9}{N_{\eta,|y|<y_{\mathrm{max}}}}$$

- reconstruction efficiency:

$$\epsilon_{\text{reco, }\eta} = \frac{\text{verified } \; N_{\pi^0(\eta),\mathrm{rec}} \, (p_{\mathrm{T,\ rec}})}{N_{\eta,|y|<y_{\mathrm{max}}} \text{ with daughters within } |\eta_\gamma| < 0.9(p_{\mathrm{T,\ MC}})}$$

→ ϵ_{rec} shape determined by the shape of conversion probability ($\approx 8\%$) and photon reconstruction efficiency

→ decrease in efficiency from peripheral to central collisions due to smaller single particle reconstruction efficiency with larger multiplicity