# Measurement of the $\omega$ meson in pp collisions at the LHC with ALICE


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## Introduction

ALICE [1] is a dedicated heavy-ion experiment and focuses on the properties of the Quark-Gluon Plasma (QGP), a state of strongly interacting matter expected to be formed in heavy-ion collisions.
Neutral mesons (like the $\omega$ meson) created in high energy collisions are valuable probes for the properties of the QGP, as well as particle production in general. Measurement of their production cross section have several motivations:

- **Theoretical Motivation:**
  Measurement of neutral mesons needed to test understanding of QCD and its implementation in QCD-based event generators like PYTHIA:
  - Fragmentation function and parton distribution function (needed for pQCD at high $p_T$) constrained by fitting measured data at different collision energies
  - Low $p_T$ regime described by phenomenological models: need to be verified by meson measurements
- **Experimental Motivations:**
  - Photons produced during different stages of collision and do not interact strongly:
    Ideal particle to probe properties of the QGP
    To acquire the fraction of direct photons [2] from all generated photons, precise measurements of neutral meson spectra need to be performed
  - Particle productions can be used to probe the QGP: QGP at high $p_T$ expected to suppress the hadron production in Pb-Pb collisions compared to pp collisions

## Event Selection

- Data used in this analysis were taken in pp collisions at center of mass energy of $\sqrt{s} = 13$ TeV
- Recorded at LHC from 2016 to 2018 and consist of minimum bias (MB) events and additional triggered events
- Triggered events require energy deposit in the calorimeters that exceed certain threshold

| data | MB | EMC-L1 (low) | EMC-L1 (high) | PHOS-L0 |
|---|---|---|---|---|
| $\mathcal{L}_{\text{int}}$ | 0.029 $pb^{-1}$ | 0.99 $pb^{-1}$ | 9.6 $pb^{-1}$ | 7.2 $pb^{-1}$ |

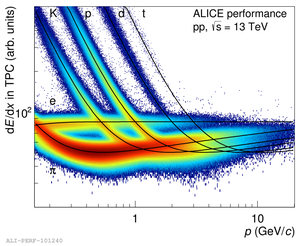
- EMC (combination of EMCal and DCal calorimeter) has two available triggers (EMC-L1 (low) and EMC-L1 (high))
- Photon Spectrometer (PHOS) has one available trigger (PHOS-L0)

## Analysis

The $\omega$ meson has a probability of $\approx 90\%$ to decay into a neutral pion and a pair of charged pions. The four momentum vectors of these three pions are summed up and the result is used to calculate the invariant mass of the $\omega$ meson.

$$\omega \rightarrow \pi^+ + \pi^- + \pi^0$$

### Charged Pion Measurement




- Time Projection Chamber (TPC) and Inner Tracking System (ITS) are used to reconstruct tracks of charged particles [3]
- Energy loss ($\mathrm{d}E/\mathrm{d}x$) in TPC is used for identification of charged particle tracks
- Coverage: $|\eta| < 0.9,\ 0^\circ < \varphi < 360^\circ$
- Charged pions with $p_T$>100 MeV are measured

## Photon Reconstruction

Three different techniques are available in ALICE to measure photons at mid-rapidity:

**Photon Conversion Method (PCM)**

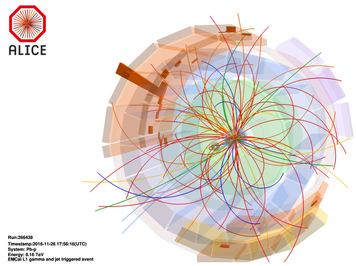
- Coverage: $|\eta| < 0.9,\ 0^\circ < \varphi < 360^\circ$
- Photons have a probability of $\approx 8.5\,\%$ to convert within inner detector material: $\gamma \rightarrow e^+ + e^-$
- Reconstruction at mid-rapidity with the TPC
- Low statistics but good resolution
- $\omega$ measurement from $\approx$ 1.6 to 13 GeV/c

**PHOS [5]:**

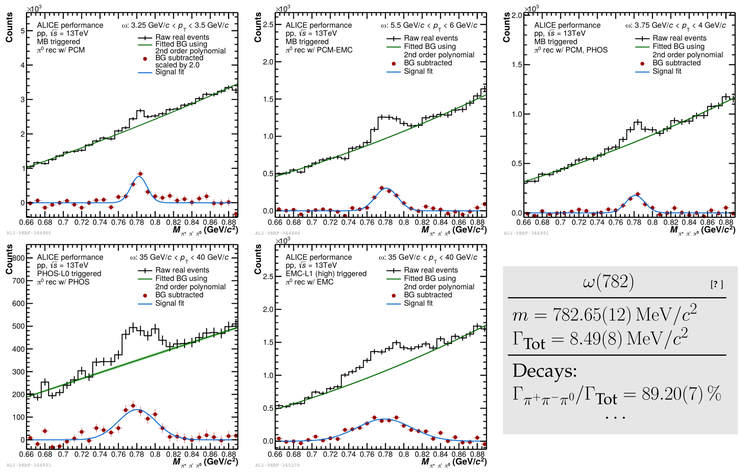
- Coverage: $|\eta| < 0.13,\ 250^\circ < \varphi < 320^\circ$
- Consists of lead-tungstate crystals
- Smaller coverage than EMCal but higher granularity
- $\omega$ measurement from $\approx$ 2 to 40 GeV/c

**EMC [4]:**

- Coverage
  EMCal: $|\eta| < 0.7,\ 80^\circ < \varphi < 187^\circ$
  DCal: $0.25 < |\eta| < 0.7,\ 260^\circ < \varphi < 320^\circ$
  and $|\eta| < 0.7,\ 320^\circ < \varphi < 327^\circ$
- Pb-scintillator with alternating lead and scintillator segments
- Designed for high-$p_T$ measurements
- $\omega$ measurement from $\approx$ 3 to 45 GeV/c




## $\omega$ Measurement in pp Collisions at $\sqrt{s} = 13$ TeV



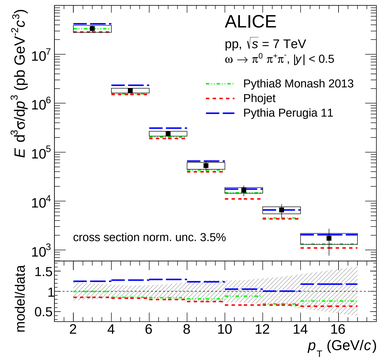

| $\omega(782)$ [?] |
|---|
| $m = 782.65(12)\ \mathrm{MeV}/c^2$ |
| $\Gamma_{\mathrm{Tot}} = 8.49(8)\ \mathrm{MeV}/c^2$ |
| Decays: |
| $\Gamma_{\pi^+\pi^-\pi^0}/\Gamma_{\mathrm{Tot}} = 89.20(7)\,\%$ |
| ... |

Neutral pions cannot be measured directly and have to be reconstructed. Their decay into two photons is used for this reconstruction. The measurement of neutral pions can be realized with five different methods:

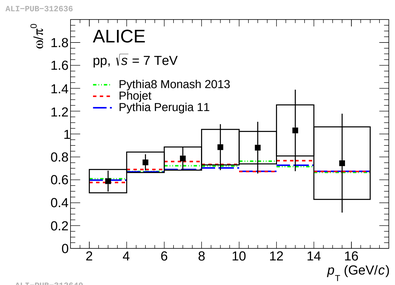
PCM-PCM, PCM-EMC, PCM-PHOS, EMC-EMC and PHOS-PHOS

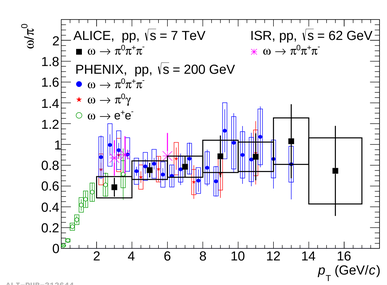
- Underlying background is described by second order polynomial fit
- To obtain $\omega$ mass position, signal distribution (background subtracted) is fitted by Gaussian with additional exponental tail (Bremsstrahlung)
- Meson yield is extracted by bin counting within two $\sigma$ of Gaussian

## Results for PHOS in pp Collisions at $\sqrt{s} = 7$ TeV




- Invariant differential cross section of $\omega$ meson production as a function of transverse momentum in pp collisions compared to model calculations from PYTHIA 8.14 (Monash 2013 tune), PHOJET and PYTHIA 6.4 (Perugia 2011 tune) [6].
- Invariant differential cross section is measured from 2 to 17 GeV/c and is in agreement with shown model calculations.




- $\omega$ / $\pi^0$ ratio [6] is compared to calculations from PYTHIA 8.14 (Monash 2013 tune), PHOJET and PYTHIA 6.4 (Perugia 2011 tune) (left) and to measurements with lower center of mass energies ([7][8][9]) (right).
- Measured $\omega$ / $\pi^0$ ratio is consistent with different shown model calculations within uncertainties
- Measured $\omega$ / $\pi^0$ ratio is in agreement with different shown center of mass energy measurements within experimental uncertainties

## Outlook

- Publication for $\sqrt{s}$=7 TeV coming soon: In addition to the PHOS method the paper will include the PCM, PCM-EMCal and EMCal methods, which results in smaller statistical and systematic uncertainties.
- Due to its high amount of statistics, the measurement in $\sqrt{s}$=13 TeV will have lower statistical uncertainties compared to this measurement. Another benefit of the $\sqrt{s}$=13 TeV measurement is its high amount of recorded triggered data, which will increase the measured $p_T$ up to 45 GeV/c.

## References


[1] K. Aamodt et al. The ALICE experiment at the CERN LHC. *JINST*, 3:S08002, 2008.

[2] Jaroslav Adam et al. Direct photon production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. *Phys. Lett.*, B754:235–248, 2016.

[3] B. Abelev et al. Performance of the ALICE Experiment at the CERN LHC. *Int.J.Mod.Phys.*, A29:1430044, 2014. arXiv:1402.4476.

[4] P Cortese et al. ALICE Electromagnetic Calorimeter Technical Design Report. Technical Report CERN-LHCC-2008-014. ALICE-TDR-14, Aug 2008.

[5] V Man'ko et al. ALICE Photon Spectrometer (PHOS): Technical Design Report. Technical Report CERN-LHCC-99-004, 1999.

[6] S. Acharya et al. Production of $\omega(782)$ in pp collisions at $\sqrt{s} = 7$ TeV. May 2018. ALICE-PUBLIC-2018-004.

[7] M. Diakonou et al. Inclusive high-$p_T$ $\omega^0$ and $\eta'$ production at the ISR. *Phys. Lett.*, B89:432–436, 1980.

[8] S. S. Adler et al. Production of $\omega$ mesons at Large Transverse Momenta in p+p and d+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV. *Phys. Rev.*, C75:051902, 2007. arXiv:nucl-ex/0611031.

[9] A. Adare et al. Production of $\omega$ mesons in p + p, d + Au, Cu + Cu, and Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. *Phys. Rev.*, C84:044902, 2011. arXiv:1105.3467 [nucl-ex].