Photon Physics in ALICE from conversion electrons

A. Marin (for the AliCE Collaboration)

- Introduction: ALICE@LHC
- Photon detection via conversion method
- Physics results with conversion electrons: CERES, STAR
- Perspectives in ALICE
- Conclusions and outlook
The Large Hadron Collider

CMS

ALICE

ATLAS

LHCb
Photon detectors in ALICE: PHOS, EMCAL, PMD
Interaction of photons with matter

- Photoelectric effect
- Compton scattering
- Pair production: $E_\gamma > 1.02\text{MeV}$

- Electromagnetic Calorimeters:
The complete photon energy is deposited in the detector (electromagnetic shower)

- Photon measurement via conversion electrons:
  Calculate photon momentum and direction by measuring $e^+/e^-$ from a single conversion in tracking detectors

  ALICE (ITS+TPC+TRD)
Photons via conversion electrons

- Identify photons converting in the beampipe, ITS and TPC
  - Clean photon identification
  - Provide directional information
    Non vertex background (important source of systematic errors in measurement of direct photons) can be rejected.

- **Good momentum resolution for charged tracks**
  - The best resolution at low $p_T$
  - Good resolution also at high $p_T$.

  Independent measurement of the same quantities, with different systematics compared to PHOS/EMCAL.

- **Main drawback**: knowledge of the material budget in the detector. Exact composition and geometry are needed.
  Main source of systematic errors in this method
Photon Detection in ALICE

- **PHOS** (100° x 0.24 in $\eta$)
  - high resolution (energy and spatial)
  - small coverage

- **EMCal**
  - larger coverage: 120° x 1.4 in $\eta$
  - coarser spatial resolution than PHOS
  - available in 2010

- $\gamma Z \rightarrow e^+ e^-$ Conversions (Central Barrel)
  - large coverage: 360° x 1.8 in $\eta$
  - low conversion probability (8-12%)
Momentum resolution comparison

Central Barrel, pp

Momentum resolution in central barrel very good at low $p_T$
At high $p_T$ is $<4\%$

PHOS

Graphs showing resolution as a function of transverse momentum and energy.
Experimental photon results obtained with the conversion method:

- **CERES**: R. Soualah, PhD (2009)
- **STAR**: PRC70, 044902 (2004)
The CERES experiment @CERN SPS

2000 Run:
Pb+Au @$\sqrt{s_{NN}}=17.2$ GeV

- 30x10^6 events
  - $\sigma/\sigma_{geo}=7\%$

- 3x10^6 events
  - $\sigma/\sigma_{geo}=20\%$

RICH2 mirror main conversion point 6 mm thick (5% of radiation length) $\gamma Z \rightarrow e^+e^- Z$

Sidc: vertex reconstruction, angle measurement

Rich: electron ID

TPC: momentum and electron-ID ($\sigma_{mass}\sim 3.8\%$ at $\phi \rightarrow ee$)
\[ \pi^0 \rightarrow \gamma \gamma \] reconstruction method

\[ \pi^0 \rightarrow \gamma \gamma \quad (m_{\pi^0} = 0.13497 \text{ GeV/c}^2, \text{BR}=0.98, \tau = 25.1 \text{ nm}) \]

\[ M_{\pi^0} = \sqrt{2E_{\gamma_1} E_{\gamma_2} (1 - \cos \theta)} \]
Reconstructed $\gamma$ conversion points in CERES

Before $\text{opan}_{e^+e^-}$ cut

After $\text{opan}_{e^+e^-}$ cut
Spectra of $\pi^0$ mesons

$\sigma_{\pi^0} = (7.7 \pm 0.2)\text{MeV}$

R. Soualah
The STAR Detector@RHIC

Large acceptance: $2\pi$ coverage at mid-rapidity
\( \gamma, \pi^0 \) reconstruction in STAR@RHIC

PRC70, 044902 (2004)

\( \gamma \) conversion points

Very good mass resolution
$\gamma, \pi^0$ spectra in AuAu @ $\sqrt{s_{NN}}=130\text{GeV}$

STAR Coll.
PRC 70(2004)044902
Perspectives of photon physics in ALICE using the conversion method
Use TPC up to 160 cm → average radiation length ~ 8% $X/X_0$ for $|\eta| < 0.9$

$(6.5\% \times X/X_0 \text{ ITS} + 1/2 \times 3.5\% \times X/X_0 \text{ TPC})$
$\gamma$ reconstruction

$\varepsilon_\gamma^{\text{Global}} = \gamma \text{ Conversion Probability} \times \varepsilon_\gamma^{\text{reconstruction}}$
Photon physics

**Why?** Do not interact strongly. Carry information about the early state. Calibrated baseline

- **Measurement of** $\pi^0$ and $\eta$ **mesons in** pp@ 10TeV
  - Highest energy available in lab
  - Test of pQCD cross section predictions
  - Reference data for PbPb
  - Main source of background in direct photon measurement

- **Measurement of Direct photons in** pp@10TeV
  - Highest energy available in lab
  - Test of pQCD cross section predictions
  - Reference data for PbPb

- **$\gamma$-Jet ($\gamma$-hadron):**
  - Study quark energy loss in the medium
  - Fragmentation function: $E_{\text{jet}} \sim E_\gamma$
How many direct photons?

... but $\gamma/\pi^0 = 0.01$-0.1 for $p_T > 20$ GeV/c

We need a good distinction direct/decay $\gamma$
\( \pi^0 \rightarrow \gamma\gamma \) reconstruction

\( \gamma, \pi^0 \) reconstruction

\( e^+, e^- \)
**γ γ Invariant Mass Spectra (π⁰ pt bins)**

Analysis in $|\eta| < 1.2$
Reconstructed $\pi^0$ Mass and Width
Photon detector resolutions

<table>
<thead>
<tr>
<th>Detector</th>
<th>$\sigma_E/E$ (%)</th>
<th>$\sigma_x$ (mm)</th>
<th>$R_{ip}$ (cm)</th>
<th>$\sigma_\pi$ (MeV)</th>
<th>$p_\ell=1-2$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHOS</td>
<td>$\sqrt{\left(\frac{1.3}{E}\right)^2 + \frac{1.3^2}{E} + 1.12^2}$</td>
<td>$\frac{3.26^2}{E} + 0.44^2$</td>
<td>460</td>
<td>5.5 MeV</td>
<td></td>
</tr>
<tr>
<td>EMCAL</td>
<td>$\sqrt{\left(\frac{11.3}{E}\right)^2 + \frac{1.7^2}{E} + 4.8^2}$</td>
<td>$1.5 + \frac{5.3}{\sqrt{E}}$</td>
<td>428</td>
<td>16 MeV</td>
<td></td>
</tr>
<tr>
<td>ITS+TPC+TRD</td>
<td>2</td>
<td>~1</td>
<td>&lt; 160</td>
<td>3.3 MeV</td>
<td>0.8 $&lt; p_\ell &lt;$ 2 GeV</td>
</tr>
</tbody>
</table>

D. Peressounko@QM09
\[ E \frac{d^3 \sigma}{dp^3} = \frac{1}{2 \pi p_T \Delta p_T \Delta y} \cdot \frac{1}{Lt \cdot \text{DutyFactor}} \cdot \frac{1}{Acc \cdot \text{Eff}} \cdot N_{\pi^0} \]

\[ \frac{dN_{\pi^0}}{dp_T [\text{GeV}^{-1}]} \]

- 3 days
- 1 month
- 3 months

\[ \frac{dN_{\eta}}{dp_T [\text{GeV}^{-1}]} \]

- 3 days
- 1 month
- 3 months

\[ \eta \] Expected statistics 1st ALICE year

K. Koch

\( \pi^0 \) NLO calculations from Y. Kharlov, L. Benhabib

Preliminary

Palaver SS2009 (Heidelberg)
Expected statistics for direct $\gamma$.

Preliminary

LO(Born)

1.6x10^9 pp MinBias collisions $p_T$ reach ~20 GeV

M. Rammler@Uni-Münster
\textbf{\gamma-hadron and \gamma-jet correlations}

\textbf{pp @ \sqrt{s}=14\text{TeV} (ALIROOT v4-05-Release)}

\gamma-jet: $6\times10^5$ events in GeV bins [5,10],[10,20],[20,30],[30,40],[40,50],[50,\ldots] in PHOS acceptance; Part of data($3\times10^5$) analysed

\begin{itemize}
  \item Isolation Cut:
  \begin{itemize}
    \item 0.2 cone size and
    \item $p_T>0.7\text{GeV}$
  \end{itemize}
\end{itemize}

\textbf{Study TRD L1Trigger possibilities needed}

A. Marin, Alice Physics Week, Prague 2008
Need for a trigger: TRD L1

Similar statistics PHOS-Central Barrel
High $-p_T$ needs a trigger

TRD L1 accept:

- $e^+e^-$ pair with high $p_T$
- Upper limit to be studied
Quarkonia and photon physics

- **J/ψ**: The smoking gun signature of deconfinement in the QGP. From suppression (SPS, RHIC) to enhancement (LHC).
  - Feed down contribution from χc & ψ' needs to be known. Measurements in pp provide the baseline.

\[
R_{\chi_c} = \frac{1}{\sigma(J/\psi)} \sum_{J=1}^{2} \sigma(\chi_{cJ}) BR(\chi_{cJ} \rightarrow J/\psi \gamma)
\]

I. Abt et al. (HERA-B),

A. Andronic et al.
ArXiv:0904.1368
$\chi_c$ detection in ALICE

$\chi_c \rightarrow J/\psi + \gamma$

$\gamma \rightarrow e^+e^-$

$J/\psi \rightarrow e^+e^-$

Reconstruct $\gamma$'s that convert in the Central Barrel material
**χ_c reconstruction**

Special events: $\chi_c \rightarrow e^+e^-\gamma$ in each minimum bias, $|\eta(e^+,e^-,\gamma)| < 1.2$

- Select $\gamma$
- Select primary $e^+e^-$
- Opening angle cut $e^+\gamma > 0.05$ rad

With e-PID using Central Barrel (TPC+18 TRD SM's)
Feasibility of $\chi_C$ measurement in pp@14TeV

How many $\chi_C \rightarrow J/\psi \rightarrow e^+e^-\gamma$ are produced/s?

$L = 10^{30}$ cm$^{-2}$s$^{-1}$; $\sigma_1 = 31.8$ µb; $\sigma_2 = 52.5$ µb

$\chi_C / s = L \times (\sigma_1 \times BR(\chi_C^1) + \sigma_2 \times BR(\chi_C^2)) \times BR(J/\psi \rightarrow e^+e^-) = 1.3 / s$

Given detection efficiency of 0.9% and acceptance of 6.3% the maximum rate of observable $\chi_C$'s is expected to be $7.4 \times 10^{-4} / s$ assuming a 100% trigger efficiency.

Alice p-resolution allows to separate the two $\chi_C$ states

- The $\chi_C$ can be measured down to $p_t \sim 0.25$ GeV/c
- Mean efficiency $\sim 0.9\%$

$\Delta M = M(e^+e^-\gamma) - M(e^+e^-)$

$P.~Gonzalez~et~al.,~EPJC$ $61$ $(2009)$ $899$
Conclusions and outlook

- Conversion method successfully used at SPS and at RHIC
- Photons can be measured with conversion electrons in the ALICE central barrel (ITS+TPC+TRD).
  - The acceptance $\times$ conversion prob. comparable to PHOS acceptance
  - Momentum resolution is very good ($\sigma_{\pi^0} = 3$ MeV at low $p_T$)
- Definition/Implementation of a high $p_T\,\gamma$-trigger in the central barrel will be study.
- Lot's of physic studies are being prepared
  - $\pi^0/\eta$ meson spectra
  - Gamma -Jet correlations
  - Direct photons
  - $\chi_c$

Careful evaluation of systematic errors is ongoing.
ALICE Detector Installation Goal 2009

**Complete:**
ITS, TPC, TOF, HMPID, FMD, T0, V0, ZDC, Muon arm, Acorde PMD, DAQ

**Partial installation:**
PHOS(3/5)
7/18 TRD
2-4/6 EMCAL

~ 50% HLT
multi–TeV cosmic ray event
Circulating Protons in LHC

ITS tracks on 12.9.2008
7 reconstructed tracks, common vertex

Circulating beam 2:
stray particle causing an interaction in the ITS
TPC commissioning

- TPC installed in ALICE, running continuously May-October 2008
- 60 million events (cosmics, krypton, and laser) recorded
- first round of calibrations completed

- performance close to design, TPC ready for collisions

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Particle identification via dE/dx

Resolution:
- measured 5.7%
- design 5.5%

A. Kalweit HK84

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Palaver SS2009 (Heidelberg)
TRD commissioning

- 4 supermodules installed in ALICE, cosmic ray data taking in 2008
- 50,000 horizontal tracks acquired (TRD L1 trigger commissioned and used)
- Reconstruction and first iteration for calibration parameters (gain, drift velocity) completed

![Diagram of cosmic event triggered by TRD L1]

![Graph showing drift velocity and uniformity]

GSI scientific report 2008

uniformity better than 10%
Ready for proton/ion beam

Formal end of ALICE installation: July 2008
Comparison to other experiments
Comparison to $h^\pm$
The charmonium system

The $\chi_c$ family:

- $\chi_{c1} \rightarrow J/\Psi + \gamma$ (35.6% decay rate)
- $\chi_{c2} \rightarrow J/\Psi + \gamma$ (20.2%)
- $\chi_{c0} \rightarrow J/\Psi + \gamma$ (1.3%) (has been neglected)
- $J/\Psi \rightarrow e^+ e^-$ (5.94%)
J/$\psi$ suppression at SPS and RHIC

PHENIX Au+Au data shows suppression at mid-rapidity about the same as seen at the SPS at lower energy
• but stronger suppression at forward rapidity.
• Forward/Mid $R_{AA}$ ratio looks flat above a centrality with $N_{\text{part}} = 100$

• Feed down contribution from $\chi_C$ & $\psi'$ needs to be known
• Measurements in pp provide the baseline
Clear signal for generation of charmonia due to statistical hadronization at the phase boundary
\( \gamma \text{ detection with conversion method} \)

\( \gamma Z \rightarrow e^+e^-Z \) Conversions (Central Barrel)
- large coverage: 360° \( \phi \times 1.8 \) in \( \eta \)
- low conversion probability (8-12%)

• Identify photons converting in the beampipe, ITS and TPC
  
  Clean photon identification
  Provides the \( \gamma \bar{p} \)
  
  Non vertex background can be rejected.
  
  Very good momentum resolution for charged tracks
PHOTON SPECTROMETER

- Dense like lead and transparent like crystal to stop photons
- PbWO$_4$ crystal (17920 crystals in total)
  - $R_M=2.2$ cm, $X_0=8.9$ mm, $\rho=8.28$ g/cm$^3$,
  - $n=2.16$, size: $22 \times 22 \times 180$ mm$^3$

PHOS foresees 5 modules installed at 4.6 m apart from the ALICE interaction point.
$\pi^0$, $\gamma$ reconstruction in STAR@RHIC
Radiation length

by Y.S. Tsai [36]:

\[
\frac{1}{X_0} = 4\alpha r^2 \frac{N_A}{A} \left\{ Z^2 [L_{\text{rad}} - f(Z)] + Z L_{\text{rad}}' \right\}.
\] (27.20)

For \( A = 1 \text{ g mol}^{-1} \), \( 4\alpha r^2 N_A/A = (716.408 \text{ g cm}^{-2})^{-1} \). \( L_{\text{rad}} \) and \( L_{\text{rad}}' \) are given in Table 27.2. The function \( f(Z) \) is an infinite sum, but for elements up to uranium can be represented to 4-place accuracy by

\[
f(Z) = a^2 \left[ (1 + a^2)^{-1} + 0.20206 -0.0369 a^2 + 0.0083 a^4 - 0.002 a^6 \right],
\] (27.21)

where \( a = \alpha Z \) [37].
Radiation length

Although it is easy to use Eq. (27.20) to calculate $X_0$, the functional dependence on $Z$ is somewhat hidden. Dahl provides a compact fit to the data [38]:

$$X_0 = \frac{716.4 \text{ g cm}^{-2} A}{Z(Z + 1) \ln(287/\sqrt{Z})}. \quad (27.22)$$

Results using this formula agree with Tsai’s values to better than 2.5% for all elements except helium, where the result is about 5% low.

The radiation length in a mixture or compound may be approximated by

$$1/X_0 = \sum w_j/X_j, \quad (27.23)$$

where $w_j$ and $X_j$ are the fraction by weight and the radiation length for the $j$th element.

Both the geometry of the detector and the exact material composition are needed
NLO calculations for $\pi^0$
(Y. Kharlov, L. Benhabib)

$\pi^0$ cross section

run time

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<table>
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<tbody>
<tr>
<td>3 days</td>
<td>1.3nb$^{-1}$</td>
</tr>
<tr>
<td>1 month</td>
<td>13nb$^{-1}$</td>
</tr>
<tr>
<td>3 month</td>
<td>39nb$^{-1}$</td>
</tr>
</tbody>
</table>

Palaver SS2009 (Heidelberg) 7/15/2009
The CERN accelerator complex

LINAC2- BOOSTER-PS-SPS-LHC