R&D FOR THE UPGRADE OF THE HIGH MOMENTUM PARTICLE IDENTIFICATION DETECTOR FOR ALICE AT LHC

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on behalf of the ALICE/VHMPID collaboration
Outline

- Physics motivation for a Very High Momentum PID upgrade
- New design specifications and related R&D
- Expected performance
- Testbeam studies
- Summary
PID in ALICE

- ALICE specifically designed to study Quark-Gluon Plasma in “heavy ion collisions” at LHC, pp studies relevant part of the physics program

- Excellent PID capabilities by combining different techniques over a large momentum range
Physics motivation

- The Very High Momentum PID (VHMPID) RICH has been proposed as additional detector to extend charged hadron track-by-track PID capability up to 25 GeV/c and complement the existing measurements based on statistical methods (dE/dx), addressing specifically the study of jets properties.

- The latest proposal foresees the combined integration of an EMCAL and a RICH in the same acceptance to achieve direct reconstruction of the full jet and its energy, thus significantly improving the track-by-track physics and correlation measurements (jet-hadron, di-hadron).

- Such an integrated detector system will provide major contribution in the determination of particle identified fragmentation functions both in pp and in heavy ion physics.
Design specifications and R&D issues I.

First VHMPID proposal in 2006, various layouts studied; after first LHC results at the end of 2011, new specifications requiring further R&D:

- Charged hadrons (π, K, p) identification in 5 - 25 GeV/c and combined integration with EMCAL extension (DCAL) -> Cherenkov radiator
  - K identification starting at 5 GeV/c not possible with any gaseous radiator at atmospheric pressure: increase radiator gas pressure to lower Cherenkov threshold
  - After discontinuing of production by 3M, poor UV transparency and larger cost of C₄F₁₀ available on the market: new radiator gas C₄F₈O, tested for BTeV RICH in the visible, first use in UV. 2nd option: C₅F₁₂.
  - Max detector depth ~70 cm (limited “free” space) pushes for a compact detector

**Focusing RICH with pressurized C₄F₈O gaseous radiator**
Cherenkov radiator gas pressurization

- Refractive index optimization

<table>
<thead>
<tr>
<th>P [bar]</th>
<th>Refr. ind.@ 175 nm</th>
<th>Momentum threshold [GeV/c]</th>
<th>N_ph cm^{-1} eV^{-1} at saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \pi )</td>
<td>( K )</td>
<td>( p )</td>
</tr>
<tr>
<td>1</td>
<td>1.00153</td>
<td>2.5</td>
<td>9</td>
</tr>
<tr>
<td>1.5</td>
<td>1.002295</td>
<td>2.1</td>
<td>7.3</td>
</tr>
<tr>
<td>2</td>
<td>1.00306</td>
<td>1.8</td>
<td>6.4</td>
</tr>
<tr>
<td>2.5</td>
<td>1.00383</td>
<td>1.6</td>
<td>5.6</td>
</tr>
<tr>
<td>3</td>
<td>1.0046</td>
<td>1.5</td>
<td>5.1</td>
</tr>
<tr>
<td>3.5</td>
<td>1.00535</td>
<td>1.3</td>
<td>4.8</td>
</tr>
</tbody>
</table>

- @ 3.5 bar and L= 50 cm: excellent photon yield and ring radius (5 cm) suitable for pattern recognition
- PID range can be extended by lowering P
- @ 3.5 bar \( \text{C}_4\text{F}_8\text{O} \) needs heating at \( \sim 40 \) °C to prevent condensation
- Using \( \text{C}_5\text{F}_{12} \): \( P \sim 2.8 \) bar, \( T \sim 60 \) °C
Design specifications and R&D issues II.

- Large acceptance (up to 60 m$^2$, ~30% of the barrel) and large photosensitive area (up to 8 m$^2$) + B=0.5 T -> photon detector
  - ALICE HMPID (11 m$^2$ of CsI-MWPC) know-how, CsI-based photo-detector is the most cost effective solution
  - Modified MWPC with reduced CsI PC pad size and anode-cathode gap: improved spatial resolution + smaller induction spread (5 cm ring radius wrt 12 cm in HMPID)
  - CsI-based TGEM photon detector
  - Photonis Planacon XP85012Q with bialkali PC to work in the visible

- High luminosity ALICE upgrade (pp: up to 2 MHz, Pb-Pb: 50 KHz)
  - Front-end and readout electronics

- Other topics
  - Radiator vessel and mirror system engineering studies
  - Radiator gas cleaning and UV transparency measurement systems
  - Tracking detector based on CCC (Close-Cathode Chamber)
Baseline detector principle scheme

- Focusing RICH, $C_4F_8O$ gaseous radiator $L \sim 50$ cm, operated at 1-3.5 bar
- Al honeycomb radiator vessel, 4 mm sapphire window with A/R coating
- HMPID-like photon detector: MWPC with CsI pad segmented photocathode, operated with $CH_4$; pad size 4x8 mm$^2$, 20 µm anode wires, 0.8 mm gap, 4 mm pitch
- 50x50 cm$^2$ spherical mirror, light C-fiber substrate, Al/MgF$_2$ coating
- CCC tracking layers with strip chambers
- FEE with analogue readout for centroid measurement, three options:
  - HMPID Gassiplex chip with T/H, modified version from COMPASS RICH (max 500 KHz trigger rate)
  - APV25 with continuous sampling at 40 MHz, as used in COMPASS RICH and HADES RICH upgrades
  - new common FEE developments for ALICE high-lumi upgrade
Module arrangement under study
- 5 Central modules, size ~ 1.4x1.7x0.7 m³
- 10 Side modules, size: ~ 2.7x1.7x0.7 m³
Mirror layout studies with ZEMAX

Interaction point (IP)

Focal point for mirror 1

Focal point for mirror 2

CsI photocathode

Eta-view

Phi-view

3-D View
Detector figure of merit $N_0$

$N_0 = 370 \int \varepsilon \cdot QE \cdot T \cdot RdE$

$N_{pe} = N_0 L \sin^2 \theta_c$

<table>
<thead>
<tr>
<th>UV</th>
<th>Visible</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>130</td>
</tr>
<tr>
<td>24</td>
<td>45</td>
</tr>
</tbody>
</table>

MC simulation: 15 GeV/c $\pi$, $C_4F_8O$ @ 3.5 bar

Single photoelectrons overlap within a pad cluster: number of reconstructed photons

$N_{rp} < N_{pe}$.

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Angular resolution and particle separation

Theoretical estimation
C₄F₈O @ 3.5 bar

<table>
<thead>
<tr>
<th></th>
<th>UV</th>
<th>Visible</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_\theta) chromatic</td>
<td>2.7 mrad</td>
<td>5.3 mrad (!)</td>
</tr>
<tr>
<td>(\sigma_\theta) emission</td>
<td>0.5 mrad</td>
<td>0.5 mrad</td>
</tr>
<tr>
<td>(\sigma_\theta) granularity</td>
<td>1.7 mrad</td>
<td>1.7 mrad</td>
</tr>
<tr>
<td>(\sigma_\theta) tracking</td>
<td>1.6 mrad</td>
<td>1.6 mrad</td>
</tr>
<tr>
<td>(\sigma_\theta) total</td>
<td>3.6 mrad</td>
<td>5.8 mrad</td>
</tr>
<tr>
<td>(N_{rp})</td>
<td>~ 13</td>
<td>~ 30</td>
</tr>
<tr>
<td>(\sigma_{\theta \text{(track)}})</td>
<td>~ 1 mrad</td>
<td>~ 1.1 mrad</td>
</tr>
</tbody>
</table>

\[
\frac{\sigma_\theta}{\sqrt{N_{rp}}} = \frac{m_2^2 - m_1^2}{2n_\sigma P^2 \tan \theta_c}
\]

Signal
(GeV/c)

Absence of signal
(GeV/c)

| \(\pi\)  | 2-16 |
| \(K\)    | 5-16 |
| \(p\)    | 10-25 |

PID ranges
- Lower limit: cut \(N_{rp} > 2\)
- Upper limit: 3\(\sigma\) separation

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MC studies of PID performance

Events from single particles gun embedded in HIJING generated background (ALIROOT framework)
MC studies of PID performance

Events from single particles gun embedded in HIJING generated background (ALIROOT framework)

- Probability of identification for $\pi$, $K$, $p$
- PID algorithm based on HMPID pattern recognition (Hough transform)
- Further tuning/optimization in progress for VHMPID ring patterns
Testbeam studies at CERN PS/T10

- Prototypes using liquid C$_6$F$_{14}$ radiator (in proximity focusing, HMPID-like), and C$_4$F$_{10}$ or C$_4$F$_{8}$O at atmospheric pressure with mirror focusing
- MWPC prototype with adjustable anode-cathode gap (0.8-2 mm), smaller pad
- Prototype with C$_4$F$_{8}$O radiator pressurization and heating
- CsI-TGEM and -RETGEM as photon-detector in RICH prototype with C$_6$F$_{14}$ radiator (see V. Peskov’s talk)
Prototype with two Cherenkov radiators (Nov 2011)

**Achieved HMPID benchmark performance**

- **C\textsubscript{6}F\textsubscript{14} liquid radiator**

**Radiators**

- **Gaseous radiator**
- **Liquid radiator**

**Detectors**

- **CsI PC, 8x8 mm\textsuperscript{2} pads**
- **MWPC**
  - 20 \textmu m anode wires,
  - 2 mm gap, 4 mm pitch

**Windows**

- **SiO\textsubscript{2} windows**

**Mirror**

- **Spherical mirror**

**Gas**

- **C\textsubscript{4}F\textsubscript{10} or C\textsubscript{4}F\textsubscript{8}O radiator gas at atmospheric pressure (L = 100 cm)**
Comparison $C_6F_{14}$ /$C_4F_{10}$ /$C_4F_8O$

- $C_6F_{14}$ thickness: 6 mm, to obtain same photon yield as 100 cm gaseous radiator
- First tests with radiator gas, $C_4F_{10}$ and $C_4F_8O$ used w/o cleaning or filtering
Variable-gap chamber tests (June 2012)

- Refurbished old prototype (F. Piuz, RD26), anode-pad cathode gap adjustable in 0.8-2 mm (100 μm steps), anode wire cathode 2 mm, 20 μm anode wires, pitch 4 mm
- Basic performance studies using liquid $C_6F_{14}$ radiator, 3 mm thick: HV scan, gap scan
Variable-gap chamber tests (June 2012)

Single e- PH spectrum

Gain vs HV at various gaps

slope -> gain $A_0$

Equal amount of photons seen @ various gaps
Variable-gap chamber tests (June 2012)

Cluster size proportional to gap

No. of raw clusters increases by reducing the gap
Testbeam with pressurized $\text{C}_4\text{F}_8\text{O}$ radiator (Oct 2012)

- Safety pressure test (@ 5 bar for 5 h)
- Heating studies with Fluent 6.0 to optimize insulation and ensure radiator temperature uniformity

Radiator equipped with heating tape and P, T probes.
Testbeam with pressurized $C_4F_8O$ radiator (Oct 2012)

P, T monitoring and control panel

Gas system, piping and detector heated and insulated
Testbeam with pressurized $C_4F_8O$ radiator (Oct 2012)

The first 15 events for $C_4F_8O$ at 3.5 bara with 6 GeV/c $\pi^-$ beam
Testbeam with pressurized $C_4F_8O$ radiator (Oct 2012)
Testbeam with pressurized $C_4F_8O$ radiator (Oct 2012)

Few % K’s contamination: detected and identified

$C_4F_8O$ refractive index in UV $\sim C_4F_{10}$, simulation are in progress to deduce exact parameterization
Testbeam of CsI-TGEM photon detector with $C_6F_{14}$ liquid radiator (2011)

- Observed detection efficiency ~ 60% of HMPID, Gassiplex not optimized for TGEM
- First tests performed with APV25 and in progress
- New tests planned with larger TGEM
Due to delay on electronics production, it could not be tested before the end of testbeam at CERN/PS in 2012

Planned lab tests with LED source

<table>
<thead>
<tr>
<th>Description</th>
<th>Window material</th>
<th>UV-Glass, Schott 8337B or equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photocathode</td>
<td>Bialkali</td>
<td></td>
</tr>
<tr>
<td>Multiplier structure</td>
<td>MCP chevron (2), 25 ( \mu )m pore, 40:1 L:D ratio</td>
<td></td>
</tr>
<tr>
<td>Anode structure</td>
<td>8x8 array, 5.9 / 6.5 mm (size / pitch)</td>
<td></td>
</tr>
<tr>
<td>Active area</td>
<td>53x53 mm</td>
<td></td>
</tr>
<tr>
<td>Package open-area-ratio</td>
<td>80%</td>
<td></td>
</tr>
</tbody>
</table>

![Typical spectral response](image)

### Pro’s

- Larger photon yield (larger bandwidth in visible), intrinsically faster
- No issues from radiator gas transparency (purity, \( O_2 \) and \( H_2O \) contamination), less demanding systems
- Can be mounted inside radiator vessel, sapphire windows not needed
- Commercial device, savings on work for photon detector, no \( CH_4 \) gas system

### Con’s

- Cost (~ 8.8 K$ /piece) and timescale for full production
- Chromatic error due to larger bandwidth, (compensated by photon yield, final performance similar to UV)
- Detection efficiency losses due to 80% packing factor

LAPPD ALD-MCP (A. Elagin’s talk) could be a further option depending on R&D timescale
Summary and outlook

- Intense R&D campaign has been performed in 2011/12 to meet new design requirements
- Successful tests of $\text{C}_4\text{F}_8\text{O}$ as Cherenkov radiator in UV, proven preliminary design concepts for pressurization/heating
- Baseline solution for photon-detector: CsI-MWPC with thin gap; new prototype with final layout successfully tested in Dec ‘12
- Further activities
  - continue tests on CsI-TGEM and Planacon, for “faster” detector option
  - FEE and readout electronics development
  - engineering studies on vessel structure and mirror system
- LoI submitted this week to the ALICE Collaboration, final decision in March
Letter of Intent

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plus former contributions from CERN & Yale

plus future contributions from LLNL
BACK-UP SLIDES
Material budget

<table>
<thead>
<tr>
<th>Detector component</th>
<th>X/X₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom+top radiator vessel sandwich panel</td>
<td>7%</td>
</tr>
<tr>
<td>Photon detector + tracking layers</td>
<td>3%</td>
</tr>
<tr>
<td>C-fiber mirror substrate</td>
<td>2%</td>
</tr>
<tr>
<td>Radiator gas at 3.5 bar</td>
<td>4%</td>
</tr>
<tr>
<td>Sapphire window</td>
<td>6%</td>
</tr>
<tr>
<td>total</td>
<td>22%</td>
</tr>
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</table>

For comparison:
- ITS + TPC ~ 15% X₀
- TRD ~ 26% X₀
- TOF ~ 20% X₀
Radiator refractive index and QE curves