R&D on Astroparticles
Detectors
(Activity on CSN5 2000-2003)
Introduction

- Results obtained with the R&D activity (2000-2003) with some drift chambers prototypes are reported.

- With different photocathode structures and new focusing electrodes configurations we obtained a good time-space resolution and a first rate background rejection.
"A WIMP detector with two-phase Xe"


- We describe an important new technique to search for WIMPs:
  - a) method of background discrimination using double phase Xe as detector target;
  - b) ratio between primary scintillation and secondary scintillation;
  - c) special PM with magnesium fluoride window and relative high Q.E. (> 30 %) have been used.
R&D Motivations 2

“Measurement of scintillation amplification in Xe-detector with CsI luminescence plate”


- We describe the work of our team at CERN, which uses a two-phase Xe detector with a CsI internal Photocathode. We point out a powerful method for amplifying photons in the WIMPs detector;

- With this setup, one photoelectron produces more than 180 luminescent photons;

Taking CsI Q.E. into account, the overall amplification factor of at least 10 was achieved using the new technology improvement.
Set up & results

- a) CERN, INFN To: Two-phase Xenon WIMPs Detector with powerful background discrimination

- b) Secondary vs primary scintillation plot in two-phase with mixed gamma and neutrons sources (the secondary scintillation photons are produced by electro-luminescence process in gaseous Xe)
Novel photosensitive gaseous detectors

- We have developed and successfully used several innovative designs of detectors with solid photo-cathodes.

- The main advantage of these detectors is that rather high gains (> 10^4) can be achieved in a single multiplication step.

- The aim of this work is to demonstrate that costly photo-multiplier could be replaced by cheap novel photosensitive gaseous detectors: wire counters, GEMs or glass capillary plates coupled with CsI photo-cathodes.

- The main advantages of these types of detectors are that their sensitivity could be expanded from VUV up to visible light by choosing the photo-cathode material and that they have a very good (<1 ns) time resolution.

- The main focus of our report is new fields of applications for this detectors and the optimization of their designs for such purposes.
Detection of primary scintillation photons from dense noble gases

- As suggested earlier, GPMs with CsI photo-cathodes can be used to detect the primary scintillation photons from noble elements in two-phases.

- We have performed systematic measurements with Ar, Kr and Xe gases at pressures in the range of 1-50 atm as well as some preliminary measurements with liquid Xe and liquid Ar.

- With the gaseous detectors we have succeeded in detecting a scintillation photons produced by 22 keV X-rays with an efficiency close to 100%.

- We also detected the scintillation photons produced by beta's (5 keV deposit energy) with an efficiency close to 25%.
Most of the CsI photo-cathodes used were prepared at CERN.

To avoid photochemical reaction of CsI with the Cu the GEM and the optimizes GPM electrodes were covered in advance with Ni/Au layers.
 CsI deposition system at CERN

- A. Braem lab’s is the most attractive facility for any kind of CsI deposition; we are really indebt with his team for the “open mind” solutions and suggestions.
Experimental set up

- The setup consists of essentially two parts: a scintillation chamber and a gas chamber containing the test detectors.

- Basically, it contains a scintillation chamber, separated by windows from the GPM and the PM.

- In some tests no separation window was used between the scintillation chamber and GPM.

- Inside the scintillation chamber, a radioactive source was installed: $^{241}\text{Am}$, $^{109}\text{Cd}$ or $^{90}\text{Sr}$. 
Gas system and GPM&PM set-up

- The scintillator chamber could be pumped and/or filled with noble elements: Ar, Kr and Xe at a pressure $p=1-50$ atm or in liquid phase.

- The GPMs were used: a single-wire counter (SWC) with CsI cathode, double GEM operating in tandem, capillarity plates operating and an home made GEM/capillarity-type detector.

- The SWC had the diameter of the cathode cylinder of 3.8 cm and the diameter of the gold-coated tungsten anode wire of 80 micro.
**Measurement conditions**

a) To achieve the highest possible Q.E. its design had a special feature: the disc (22 mm in diameter) covered with a CsI layer was placed at the distance of 8 mm from the anode wire;

b) Two size of GEMs were used: 3x3 and 10x10 cm² (in all measurements they were used in tandem);

c) Two types of configurations were tested; either they were combined with CsI photo-cathodes placed a few mm apart from the first GEM, or the upper GEM was covered with a CsI photosensitive layer.

d) Capillarity plates had a diameter of 20 mm and the size of holes was 100 micro. As with GEMs, they operated in tandem and were combined with CsI photo-cathodes. It was made from G10 plate, 2 mm thick with drilled holes, 1 mm diameter each.

e) The detector was operated in a single-step configuration only.

f) A charge-sensitive preamplifier Ortec 142 PC was connected to the anode wire; when necessary, the signals were additionally amplified by a Research Amplifier Ortec 450.

g) The PM used was EMI-9426 with MgF₂ window. Signals from the GPM and the PM were recorded on a LeCroy digital oscilloscope.
Oscillograms of the signals from GMP and the PM

- a) GMP signals (upper beam);
- b) PM signals (middle beam);
- c) pulse height spectrum (lowest beam).
Signals from optimized GPM&PM

- a) typical signal of background event crossing the plate;

- b) typical signals from GPM and PM;

- c) to achieve the highest possible Q.E.
Very encouraging preliminary results were obtained.

- One should note that in the last few years there have been intense developments of various types of GPMs: based not only on wire types of detectors, but also on GEM, MICROMEGAS, and glass capillary plate (CP).
- We performed comparative studies of various types of GPMs for this particular application.
- Optimization of the GPM for the detection of the scintillation photons from the noble elements.
- In most measurements, the gas chamber was separated from the scintillation chamber by a CaF2 window.
- A few tests were done without the separating window when the scintillating chamber and the detector operated in the same noble gas.
- The following standard designs of GPM were used for comparative studies: MWPC, PPAC, GEM and MICROMEGAS.
- In the case of the MWPC and the PPAC, designs with only reflective CsI photo-cathodes (400 nm thick) were used. In the case of the GEM and MICROMEGAS, both designs with reflective and semi-transparent (20 nm thick) photo- cathodes were tested.
In addition...

- We also tested two innovative designs of GPMs: a CP and a photo-sensitive RPC.
- CPs with capillary hole diameters ranging from 12 to 700 micro were studied.
- In these studies only capillaries with reflective photo-cathodes were tested: with the cathodes coated by CsI layer and with both cathodes and inner walls of capillaries coated by CsI.
- The design of the RPC was the following: the 5 cm diameter anode disc was made of Pestov glass with a resistivity of $10^{10}$ ohm.cm; the cathode was a metallized (~10 nm of Cr) CaF$_2$ disc (the entrance window) coated with a semi-transparent 20 nm tick CsI layer; the gap between the electrodes was 0.5 mm.
- All detectors were tested in a mixture of Ar or He with various quenchers (CO$_2$, CH$_4$, C$_2$H$_6$, C$_4$H$_{10}$) at p=1 atm. In some cases ethyl-ferrocene vapors were added to these mixture to better suppress ion and photon feedbacks.
...in addition

- There was also a possibility of introducing a $^{55}$Fe radiation source inside the drift gap (in the case of PPAC and RPC - directly inside the detector volume) of any of the above described detectors.

- From the ratio of the amplitude of the signal produced by the $^{55}$Fe and the signal due to the scintillation photons, one could estimate the number of detected photoelectrons.

- To estimate the Q.E. measurements in an ionization chamber mode were done with a Hg lamp used as a light source.

- In the case of the measurements without the separating window, tests were done with GEMs and CPs (100 micro holes diameter) with only their cathodes coated by a CsI layer.
Results: detectors with window

- Our main results obtained with various detectors in He-based mixtures can be summarized as follow: the gas mixture for each detector was optimized to find the best compromise between the maximum achievable gain without feedback and sufficient Q.E.
- Note that only data for CPs with 100 micro hole diameters are included (this geometry offers the maximum gas gain).
- In our experiments, the Q.E. of the CsI photo-cathodes varied from detector to detector.
- The measurements in the ionization chamber mode, however (measurement for each particular detector of the photocurrent produced by the Hg lamp), allowed necessary corrections to be made (see the correction factor n, which includes current, geometrical and CsI coating area corrections) and thus all detectors could be compared in such a way as if they had the same Q.E.
Efficiency (to Xe scintillation photons of various window-type GPMs)

<table>
<thead>
<tr>
<th>GPM type</th>
<th>Optimized gas</th>
<th>safe gain</th>
<th>QEs (%), n</th>
<th>Qer (%), n</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWPC</td>
<td>He+20% CH4+EF</td>
<td>3.104</td>
<td>4.3 (1.0)</td>
<td>11.2 (1.25)</td>
</tr>
<tr>
<td>PPAC</td>
<td>He+1% CH4+EF</td>
<td>105</td>
<td>6.7 (2.1)</td>
<td>17.3 (1.0)</td>
</tr>
<tr>
<td>RPC</td>
<td>He+1% CH4+EF</td>
<td>105 - 5.105</td>
<td>3.2 (2.2)</td>
<td></td>
</tr>
<tr>
<td>MICROMEGAS</td>
<td>He+5% CH4</td>
<td>104</td>
<td>5.3 (2.4)</td>
<td></td>
</tr>
<tr>
<td>GEM</td>
<td>He+10% CO2+EF</td>
<td>103</td>
<td>1.9 (2.6)</td>
<td>3.1 (1.6)</td>
</tr>
<tr>
<td>CP (CAT mode)</td>
<td>He+3% C4H10+EF</td>
<td>3.103</td>
<td>1.8 (2.7)</td>
<td>2.6 (2.0)</td>
</tr>
</tbody>
</table>
From the data presented, one can see that among the tested detectors with reflective photo-cathodes, the highest gains and Q.Er. was achieved with the PPAC.

Wire-type detectors offer less gains and Q.E.; however, in some experimental environments they can still be very attractive since they do not have any sparking problems.

Among detectors with semi-transparent photo-cathodes, the highest gains and Q.Es. was obtained for the RPC.

One should point out the very attractive feature of this innovative photo-sensitive detector: RPCs with CsI photo-cathodes can operate at gains of up to $10^6$ without any sparking problems.

We point-out, the RPCs also have excellent time resolutions of much better than 1 ns.

Of course these conclusions are correct only for single step detectors and for the gas mixtures we tested.

For detector operating in a cascade mode or for other gas mixtures, additional studies should be done.
Results: windowless detectors

- The operation of the CPs and GEM with reflective (400 nm thick) and semi-transparent (20 nm thick) CsI photo-cathodes was studied in pure Ar, Kr and Xe at p=1-2 atm.
- The main conclusion from these studies was that both detectors could operate in noble gases only at relatively low gains < 50.
- To reach gains of > 10^3 necessary for the single electron detection, two or more CPs or GEMs operating in tandem mode are required, and this may causes additional experimental complications.
Near future...

- The following step to obtain a scale of one or two order expansion of the detector (WARP as an example) is to improve the detection efficiency of neutral particles (single pulses delayed).
Photo cathodes evolution

- A new scintillation chamber prototype conception using a CsI “chess-photocathode” configuration is under developing; such a configuration requires a very high selected trigger.
Conclusions

- The scintillator chamber prototype should be contained in a “focusing shield” to stress the events detection.
References

- L. Periale, et al. NIM A 497 (2003) 242,