Performances of a GEM-based TPC prototype for new high-rate particle experiments

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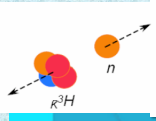
Abstract

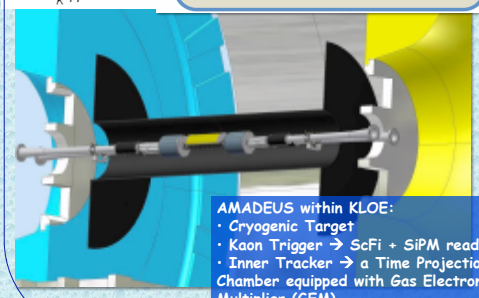
Time projection chamber (TPC) has been successfully used as a central tracker and a particle identification device in a number of a high-energy physics experiments. However, the performance requirements on TPC for new high-rate particle experiments greatly exceed the abilities of traditional TPC read out by multi-wire proportional chamber (MWPC). Gas Electron Multiplier (GEM) detector has great potential to improve TPC performances when used as amplification device. In this paper we present the R&D activity on a new GEM-based TPC (TPG) detector for the inner part of the AMADEUS experiment, a new experimental proposal at DAΦNE accelerator at Laboratori Nazionali di Frascati, aiming to perform measurements of the low-energy negative kaons interactions in nuclei (searching for the so-called "deeply bound kaonic nuclear clusters"). In order to evaluate the TPG feasibility, a 10x10 cm² prototype with a drift length up to 15 cm are designed. The performances of a 10x10 cm² pre-existing prototype with a reduced drift gap, operated with the Ar/CO_2/CF_4 (45/15/40) gas mixture and successfully tested at the BTF facility (Frascati), are presented. The gas mixture properties, such as the electron drift velocity and the diffusion, have been measured and they result comparable with those simulated with Garfield. A good resolution along the beam direction (z-coordinate), sufficient for a more large scale TPG in AMADEUS, is achieved.

The main aim of **AMADEUS** is to confirm or deny the existance of **Kaonic Cluster**, studying it in the formation and decay processes. Either situations: **EXISTENCE** or **NON-EXISTENCE** of the deeply **bound kaonic nuclear cluster** will have strong impact in kaon-nucleon/nuclei physics



AMADEUS phase-1: start in **2010/2011** (after KLOE2 step-0), study di- and tri – baryon kaonic nuclei and low-energy kaon-nucleon/nuclei interactions

AMADEUS phase-2: after 2012, higher integrated luminosity, refined study; extend to other nuclei (kaonic nuclei spectroscopy along the periodic table)



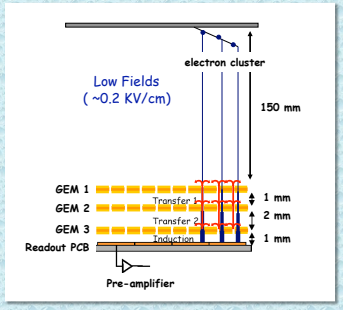
AMADEUS within KLOE:
- **Cryogenic Target**
- **Kaon Trigger → ScFi + SiPM readout**
- **Inner Tracker → a Time Projection Chamber equipped with Gas Electron Multiplier (GEM)**

GEM-based TPC requirements & challenging

Almost full solid angle coverage around the interaction area	Two cylinders TPCs along the beam pipe: Inner & Outer radius =15 & 23 cm; Length = 15 cm; Gas volume =14 l
Good spatial resolution	$\sigma_{x-y} \leq 600 \div 800$ μm & $\sigma_z \leq 300$ μm
High momentum resolution of reconstructed trajectories	$\delta_p/p \sim 1$ % (with KLOE Drift Chamber)
Low detector material, X_0 <1 %	0.5% X_0 total radiation length
Rate capability ≤ 1 kHz/cm²	Rate capability > 50 MHz/cm² (*)
Resistance against ageing effects (expected accumulated charge of ~0.05 C/cm² year)	Integrated charge of 2.2 C/cm² (**)
Operation in continuous mode	Low Ion Feedback ≈ $10^{-3} \div 10^{-4}$ (***)

(*) M. Poli Lener, Ph.D Thesis, CERN-THESIS-2006-13
(**) P. de Simone et al., IEEE Trans. Nucl. Sci. 52 (2005) 2872
(***) F. Sauli et al., CERN-PH-EP/2005-056

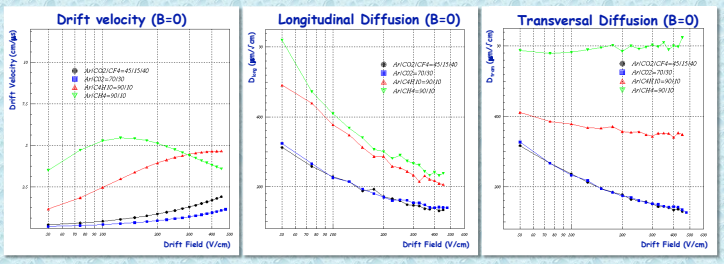
The **Gas Electron Multiplier** (F.Sauli, NIM A386 (1997) 531) is a thin (50 μm) metal coated kapton foil, perforated by a high density of holes (70 μm diameter, pitch of 140 μm)



By applying a potential between the two copper sides an electric field as high as **100 kV/cm** is produced in the holes acting as multiplication channels.
Voltages ranging between 400-500 V resulting in a gain of the order of 10^3 for a single-GEM detector.
Larger gain, up to **10^4-10^5**, in safe operating conditions, are usually achieved using **three GEM foils in cascade.**

Simulation Studies: gas mixtures & field cage design

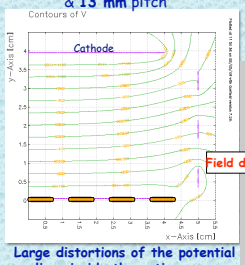
The choice of the **gas mixture** plays an important role in the **TPG resolution**, which is a compromise between high drift velocity, low electron diffusion, high radiation X_0 and no ageing



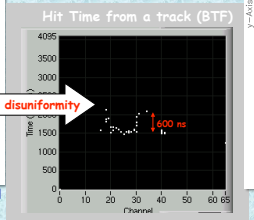
To provide a **highly uniform electric field** in the drift region, the design and the electrical properties of the field cage have been simulated with **Garfield**. The **first design** has been tested at **BTF – LNF**

Field Cage tested @ BTF:

3 Cu strips of **5 mm** length & **13 mm** pitch

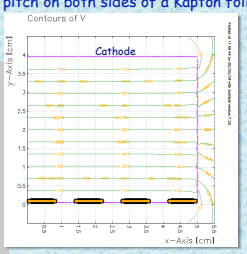


Large distortions of the potential lines inside the active area

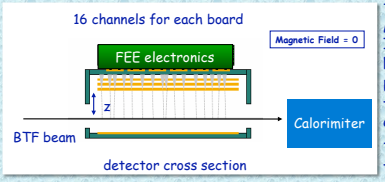


New design:

Cu strips of **2.5 mm** length & **5 mm** pitch on both sides of a Kapton foil



TPG Beam Test: setup & results

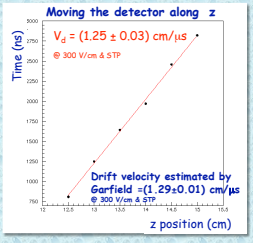


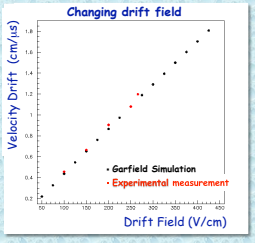
The TPG chamber has been constructed by F. Murtas in the framework of experiment IMAGEM – INFN – CSN5 for beam diagnostic purpose (Talk Wednesday 27 May).

Each FFE channel based on ADSQ chip was sent to a **multi-hit TDC** in order to record the leading edge (**hit time**) and the width of each signal.

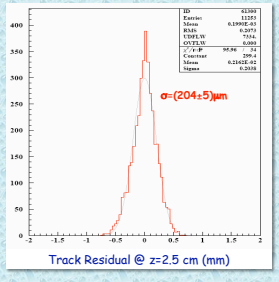
The **calorimeter** signal was used to discriminate the **number of electrons**

The electron drift velocity for the **Ar/CO_2/CF_4 (45/15/40)** gas mixture has been measured @ BTF in **two different way** and they result in agreement with **Garfield Simulation**





Knowing the linear space-time relationship, the **track residual** has been measured for different **drift distances**

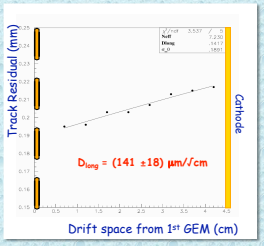


The track residual has been fitted with the function

$$\sigma_{residual} = \sqrt{\frac{D^2_{long}}{N_{eff}} * z + \sigma_0^2}$$

N_{eff}= **effective number of e⁻**

D^2_{long}= **long. diffusion**



Longitudinal diffusion estimated by Garfield

D^{Gar}_{long} = (160 ±11) μm/√cm @ 300 V/cm & STP

Conclusions

The R&D activity on TPC detector equipped with GEMs for the inner part of the AMADEUS experiment is started at LNF. A pre-existing TPG prototype with a reduced drift gap has been successfully tested at the BTF facility: the electron drift velocity and the longitudinal diffusion of the Ar/CO_2/CF_4 (45/15/40) gas mixture without magnetic field have been measured and they result compatible with those simulated with Garfield. A good resolution along the beam direction (z-coordinate) has been achieved while the analysis on multi-track separation is going on.