Why a TPC ?

E. Radicioni, M.G. Catanesi, INFN Bari

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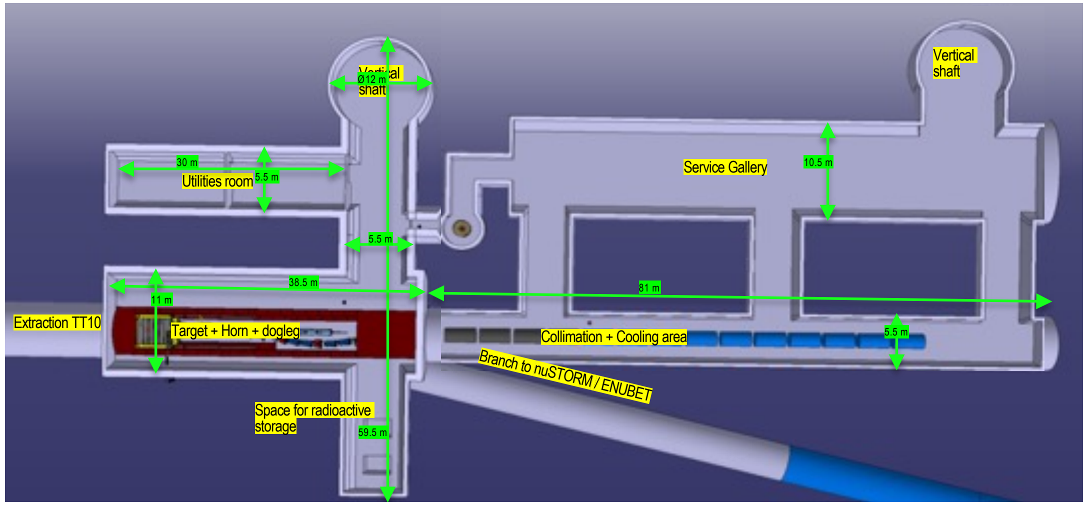
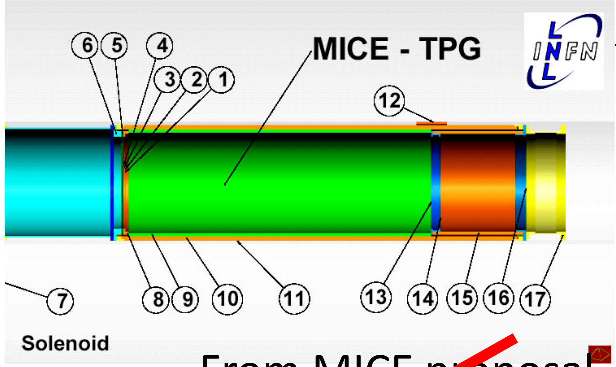
The Demonstrator will produce a large number of muons/neutrinos of few hundred MeV or less

A TPC can be used as tracker for the detection of muons in the cooling sector and/or as active target to detect neutrinos.





From MICE proposal

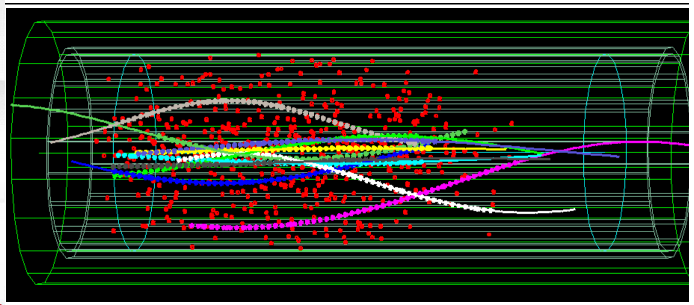
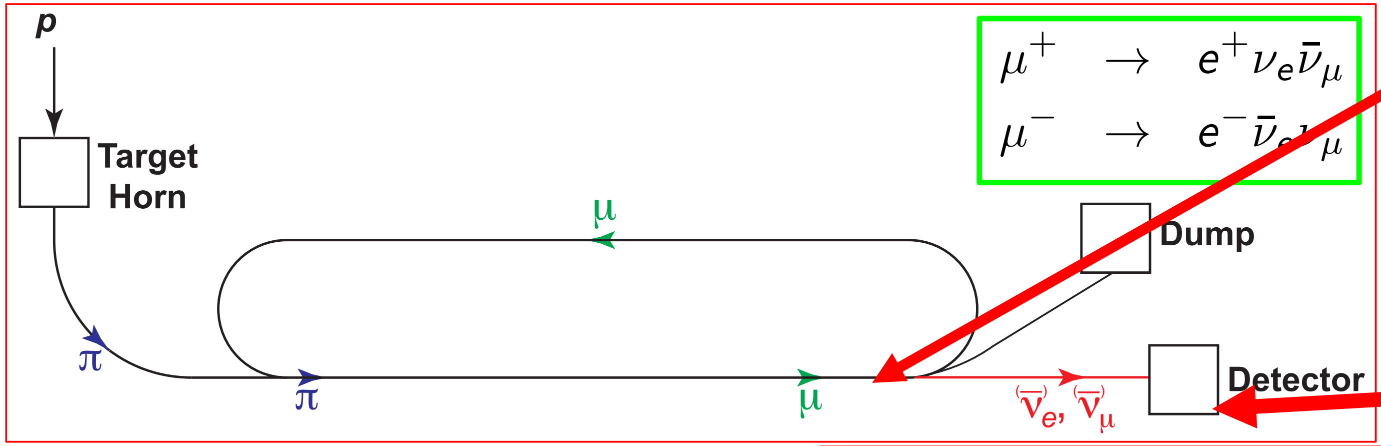
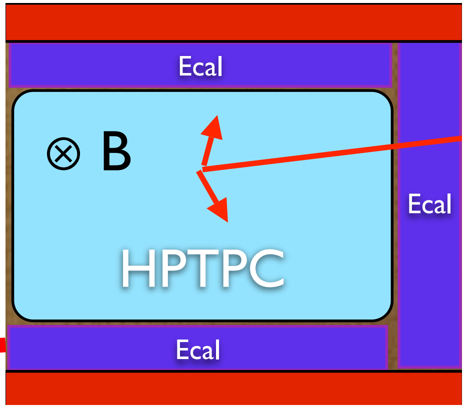


Figure 8.7: top: simulated track and noise hits in the TPG; middle: highlighted hits are those assigned by the pattern recognition to belong to the same track; bottom: track fitted on the selected hits.

a unique facility for neutrino physics and muon-collider test bed





Concept for a neutrino X-sec measurement

Why a TPC as muons monitor in the cooling sector

- It was already an option in the MICE proposal (MICE-TPG)
- 3D reconstruction capabilities
- Very low material budget (gem foils + gas (He+CH4))
- low background
- excellent track resolution
- Working principle already proved and tested in 2005

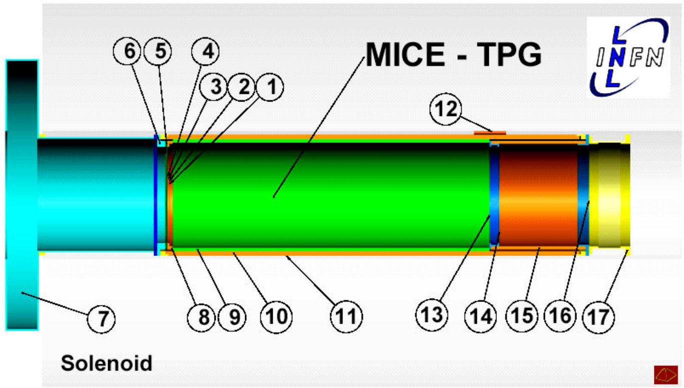
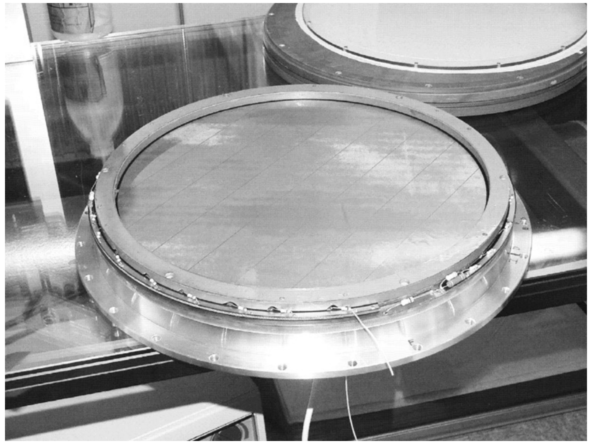
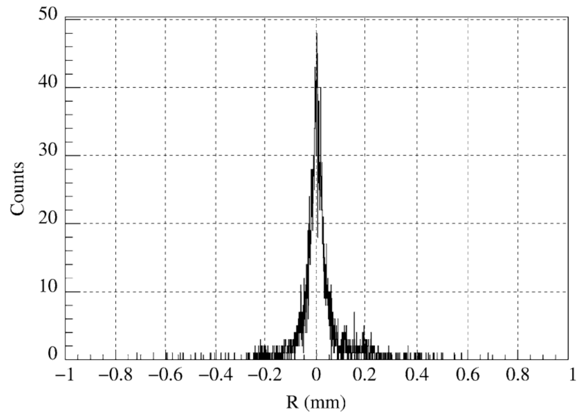


Figure 8.5: MICE-TPG upstream detector. Muon beam enters from the left. 1: GEM-1 foil; 2: GEM-2 foil; 3: GEM-3 foil; 4: hexaboard; 5: Board (for hexaboard support, gas seal and signal connectors); 6: readout flange; 7: front-end electronics support and EM shield; 8: field cage termination; 9: field cage; 10: TPG isolating container; 11: TPG peripheral grounded shield; 12: HV inlet for drift electric field; 13: HV thin metallized foil cathode; 14: HV thin metallized foil gas seal; 15: HV foil support (insulating tube); 16: grounded thin foil seal; 17: TPG–LH2-absorber integration connection flange (schematic).



hexaboard + gem foils ready to be inserted in the fieldcage



Intrinsic pad plane resolution for X-ray events FWHM ~ 40 μm

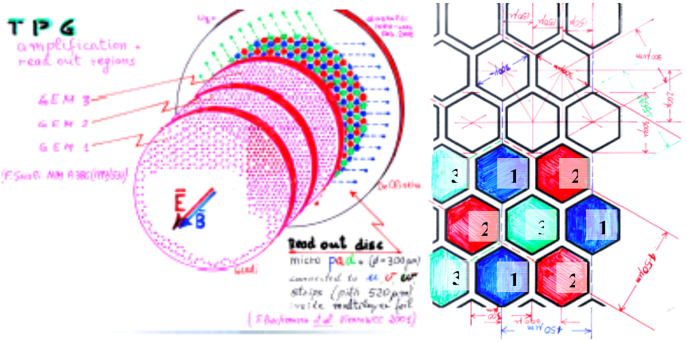
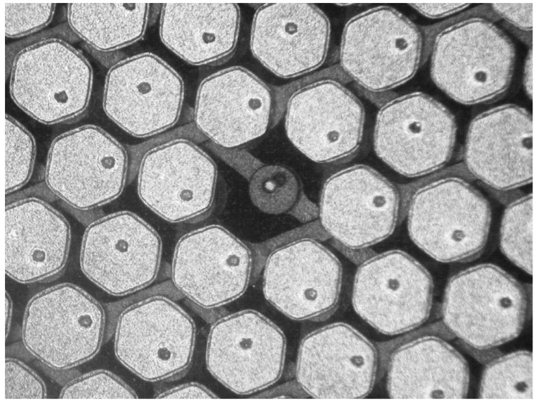


Figure 8.6: TPG readout: left: the 3 GEM foils provide amplification onto the hexaboard. Right: the hexaboard with one third of the pads (blue) connected in strips at 30°, one third at 150° (red), and one third at 90° (green).



Magnified view with pad removed with a scalpel.

Why a TPC as muons monitor in the cooling sector

- Today great improvements (and simplification) can be obtained by using the last generation of optical readouts in place of the hexagonal board+GEM proposed in 2003
- It still requires studies to find the optimal gas mixture

We propose to realize a prototype of TPC with optical readout (TimePix4 or similar) to be used as muon monitor for the demonstrator

A size of 50 length and 30cm diameter was already imagined for MICE. It could today be equipped with a more modern an optical readout.
Such a device would be lighter and tolerate a higher track density w.r.t. what was proposed 20 years ago, enhancing the advantage of multi tracks reconstruction and optimal background rejection

the development of this device is highly synergic with the development of a TPC as active target (see next slides) and both fit very well the DRD1,W8/W4 Program

This application requires non-pressurized operation

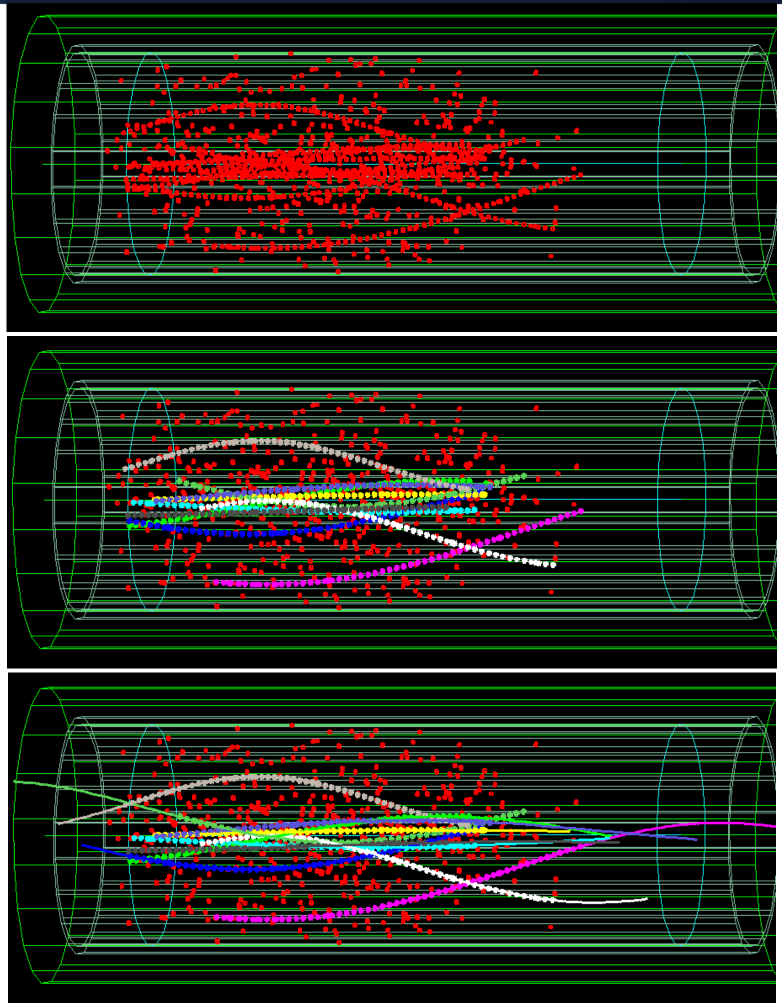
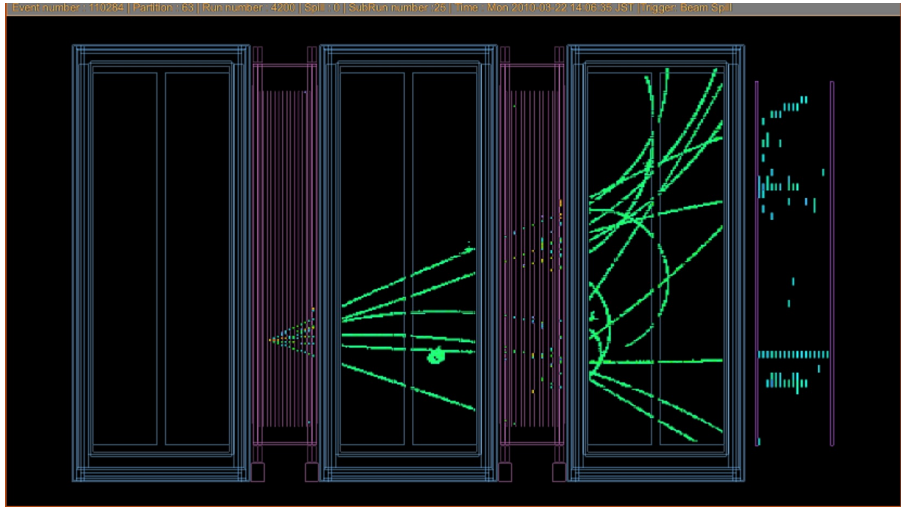


Figure 8.7: top: simulated track and noise hits in the TPG; middle: highlighted hits are those assigned by the pattern recognition to belong to the same track; bottom: track fitted on the selected hits

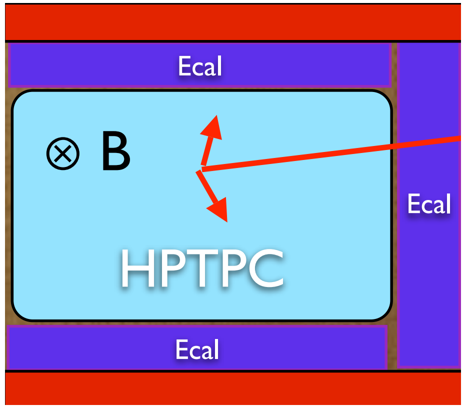
Why a TPC as neutrino detector at a demonstrator

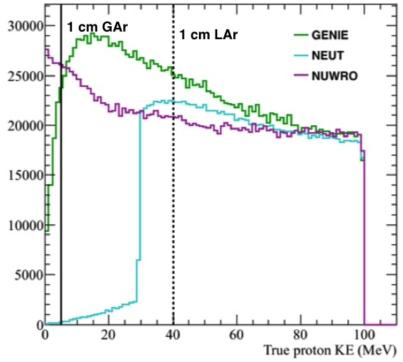
- <u>Neutrino beams from muon decays are “clean” with perfectly know characteristics → high value of data from collected interaction data</u>
- Target = detector
- 3D reconstruction capabilities.
- Possibility to exchange targets changing gas
- low density → low thresholds
- excellent PID capabilities.
- Almost uniform 4π acceptance.
- low number of interactions → requires <u>high pressure</u> and large volume.
- requires in addition a magnet to measure momentum and to distinguish between neutrinos and anti-neutrinos



A neutrino interaction in the T2K near detector

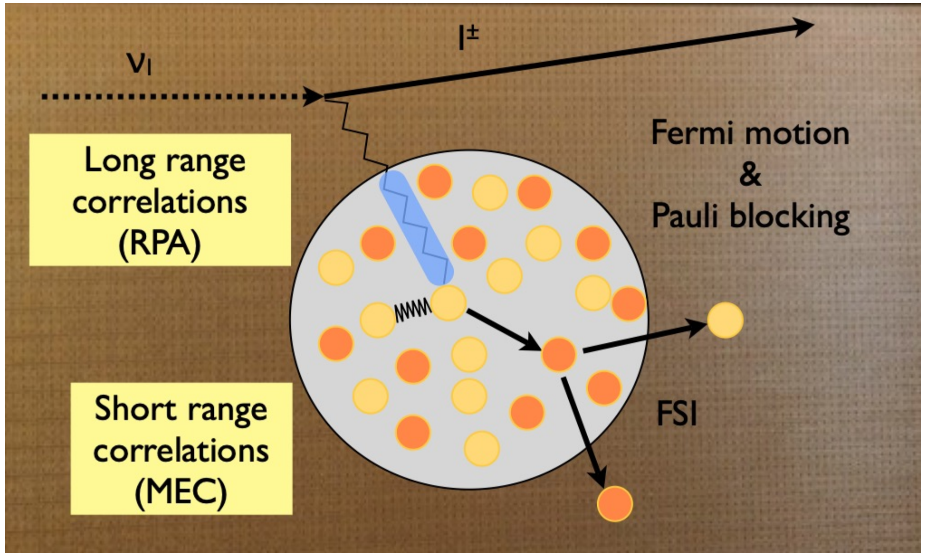
The flow of neutrinos at low energy produced by the demonstrator fit very well the requirements for a neutrino’s X-sec experiments





Differences within models are at low KE and are below the threshold of a liquid argon device

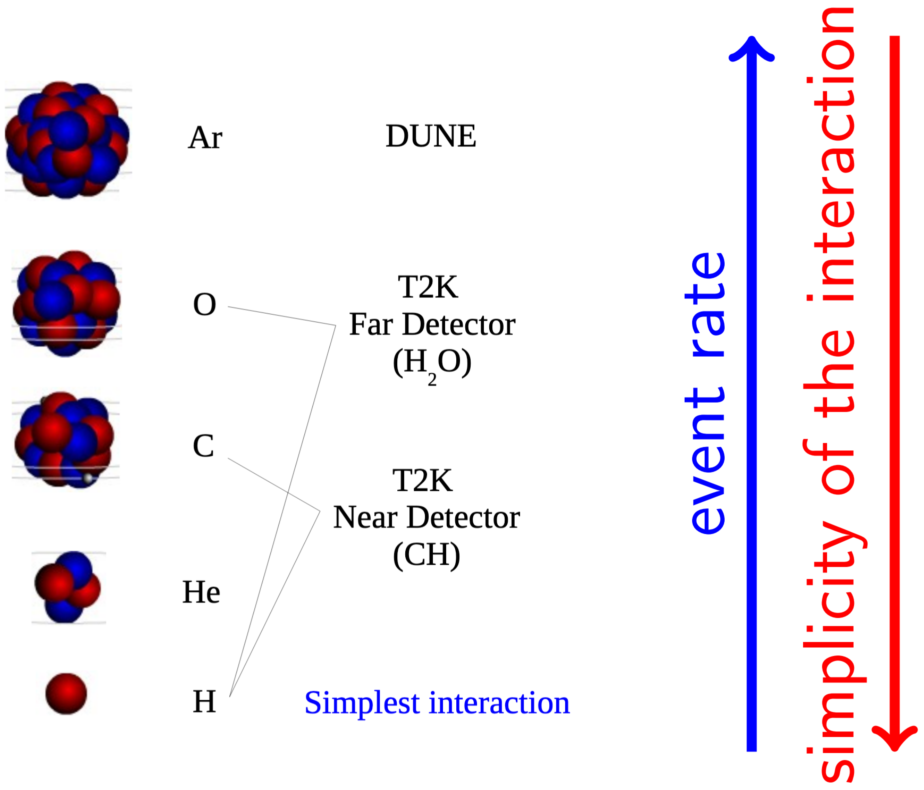
Number of events (example)



2x2x2 m^3 20°C	5 bars	10 bars
He	6.65 kg	13.3 kg
	520 evt/10^{21}pot	1040 evt/10^{21}pot
Ne	32.5 kg	67.1 kg
	2543 evt/10^{21}pot	5086 evt/10^{21}pot
Ar	66.5 kg	133 kg
	5203 evt/10^{21}pot	10406 evt/10^{21}pot
CF_4	146.3 kg	293 kg
	11450 evt/10^{21}pot	22893 evt/10^{21}pot

- As a cross-section experiment, HP-TPC allows to change the nuclear target addressing nuclear uncertainties systematics.

Different Gas mixtures for neutrino scattering experiments



- New ν-hydrogen scattering measurements are much desired for flux constraints and nucleon cross section (input for Oscillation Analysis)
- Hydrogen rich gas mixtures in a high pressure TPC could provide new data of ν-H scattering
- T2K experience + MC simulations tell us that in a HP-TPC 95 % purity for the extraction of ν-H interactions could be achieved with He-CH4 (50-50)or He-C2H6 (50-50)
- Research needed to find the ideal mixture, which still allows for safe and stable operation of a TPC

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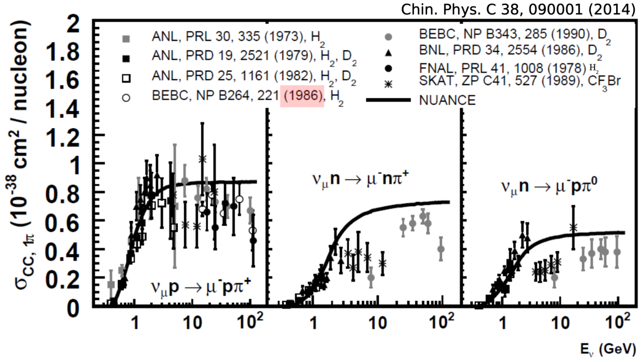
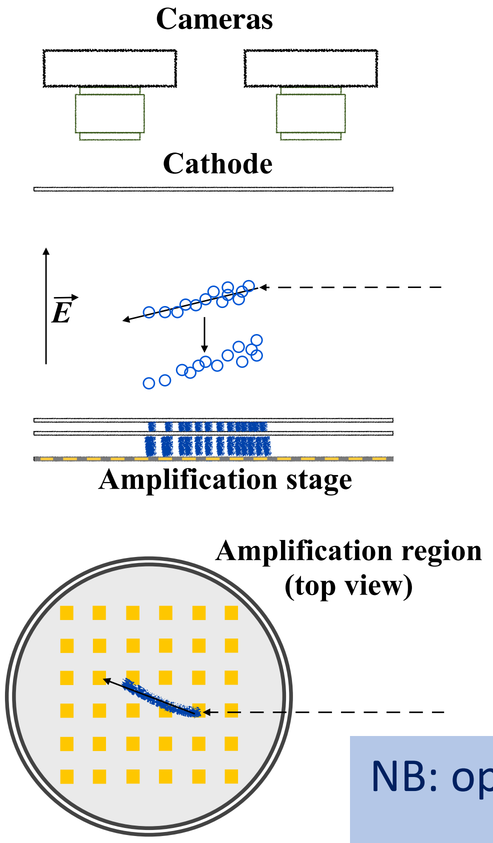


Bubbles chambers data

HPTPC with optical readout (a possible "great" improvement)



- Primary ionisations in the drift region are guided to the amplification region by an electric field
- Amplification produces electrons and photons
- Cameras image the amplification region and record a 2D projection of the electroluminescence photon
- Highly segmented readout ($\sim 100 \times 100\ \mu m^2$) at low cost per pixel possible

Current CCD cameras do not allow to access the longitudinal coordinate due to their slow readout speed

The goal is to combine optical and charge readout ➔Full 3D tracking information (since the longitudinal coordinate can be reconstructed from charge signals) ➔ (TimePix or SIPM array)

NB: optical readout is also of great interest for for the beam instrumentation case:

1) reduction of the budget material along the beam line
2) readout optimization ➔ low gas amplification factor ➔ high density of tracks

HP-TPC in DRD1

- The roadmap **of HP-TPC** is framed in **DRD1-WP8** . We are active part of the proposal for **DRD1-WP8 (but some activities are also part (synergic with) WP4)**
- We participate in a line of research on HP-TPCs for neutrino beams in collaboration with the **University of Geneva** and **IFAE Barcelona.** We have a long history of collaboration with both groups.
- The goal is to exploit the full potential of Neutrino Oscillation experiments thanks to a precise knowledge of neutrino interaction cross-sections Accessing the full phase-space of the interaction and recording all secondaries down to a few MeV/c would be the ultimate goal of a cross-section measurement. This is possible by observing interactions in a gas target by using a TPC in a magnetic field with a neutrino beam.
- The possibility of a 10-fold increase in the gas target mass by operating a TPC at high pressure is considered an enabling technique to achieve the desired statistics and measurement precision. The possibility to change the TPC gas mixture is an additional benefit, permitting a study of the A-dependence of the neutrino cross-sections on a range of different targets.
- A vessel large enough to study the effects of readout performance, drift length, attachment, etc in realistic conditions will be key in assessing the parameters for a final design of the experiment.
- The group aims, on the longer term, to evaluate possible optimizations of the dE/dx performances of such a detector by studying the cluster-counting capabilities in optical-readout mode (TimePIX or SIPM array)

HP-TPC in DRD

Possible Timescale

- 2024: Proof of operation with He/Ne and MPPC array.
- 2025: High pressure operation and stability demonstration with a small prototype
- 2026 onward: Testing with TimePix4
- *2024-2026 Construct and operate a realistic scale (50cm drift, 30x30 transverse) prototype and test facility for high-pressure with different gas mixtures and readout structures.*
- *Vessel should be large enough to be meaningful in test-beams*

Equipment available and under design

- Gas lab equipped with
- 4 gas lines including pressure control.
- readout HV system.

- A large vessel for 10 bars is being designed to host larger prototypes

Richieste 2024

Il nostro gruppo ha una lunga tradizione ed esperienza nello sviluppo e nella realizzazione di rivelatori MPGD (RD51) e di TPC in particolare. Al momento stiamo realizzando due grandi TPC con readout a MM resistive di ultima generazione e field-cage “leggere’ per l’upgrade dell’esperimento T2K in Giappone.

Le nostre richieste riguardano strumentazione presso il nostro laboratorio (ex RD51) per rivelatori a gas di Bari in modo da poter partecipare al progetto

- In particolare, si pensa di rinnovare il laboratorio
  1. attrezzando opportunamente le linee di gas esistenti al fine di testare le performances dei prototipi di TPC con diverse miscele di gas
  2. di realizzare un vessel ad alta pressione (10 atmosfere) di dimensioni tali da contenere un prototipo di 30-40cm di diametro e 50cm di lunghezza.
  3. tale vessel dovra’ essere equipaggiato con una finestra di quarzo o materiali similari allo scopo di permettere anche la lettura con dispositivi ottici.
- Una volta caratterizzato il prototipo di HP-TPC potra’ anche testato su fascio al CERN e possibilmente utilizzato per misure di fisica.
- *Le attivita’ relative allo studio delle miscele e ai test per dispositivi ottici saranno utili sia allo sviluppo di TPC da utilizzare come monitor per muoni, sia per quelle come bersaglio attivo per neutrini.*

<u>Il progetto è stato anche selezionato nell’ambito del Grant Europeo AIDAInnova i cui fondi ci permetteranno di aprire a breve una posizione di AdR dedicata a questa attività nell’ INFN.</u>

Dettaglio delle richieste

- High-pressure gas system (mass flow meters + back-pressure controller (19Keuro)

  Attualmente il laboratorio dispone solo di 3 flussimetri che non possono essere utilizzati per pressioni superiori a 2,5 bar. Abbiamo percio' bisogno di sostituirli e di aggiungerne un quarto per He.

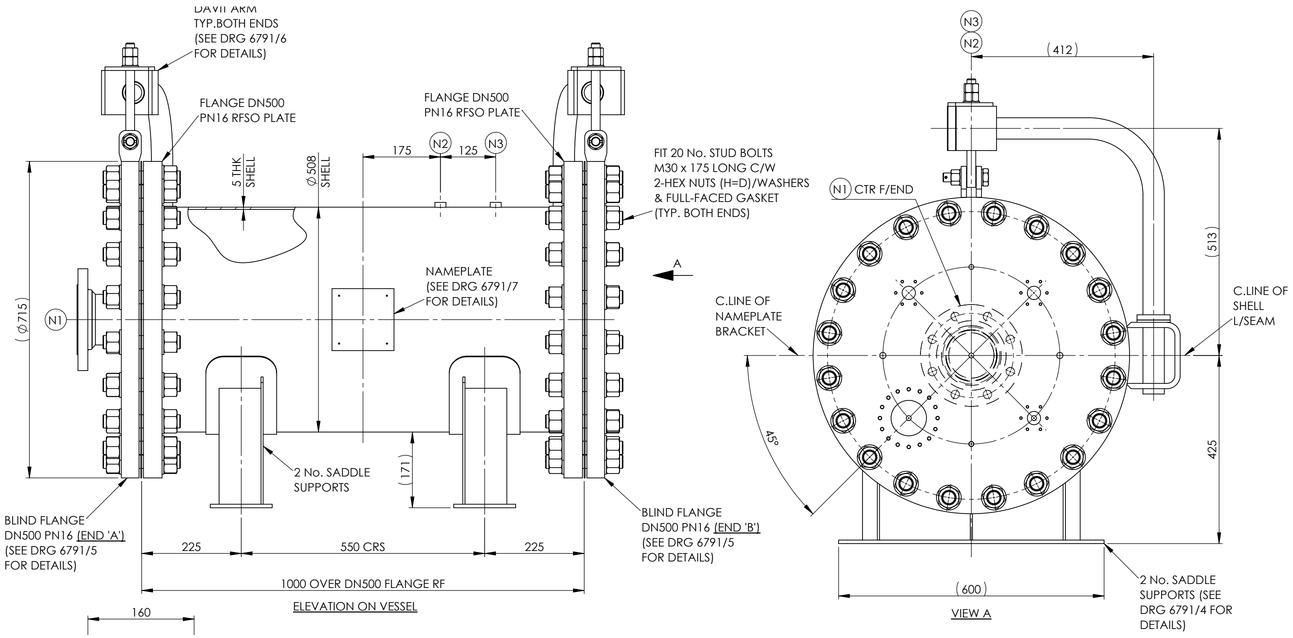
  Le stime sono basate su recenti richieste di offerta alla societa' "Precision Fluid" che commercializza in italia I flussimetri Bronkhorst

- Cathode HV supply for high-pressure gas (fino a 100KV) (21Keuro)

  Considerando una deriva di circa 50cm e una pressione di max 10 bar il catodo deve venire alimentato con una tensione fra i 60 e i 100 KV. Si tratta di un oggetto importante e fondamentale per la messa in funzione del prototipo. Da nostra ricerca l'unica ditta che ne commercializza uno in italia e' la Heinzinger di cui vi diamo il prezzi che ci ha comunicato il distributore per l'Italia (CALPower)

Experimental vessel for P=10 bar, with access ports for readout, calibration and gas mixture contamination measurement (22Keuro)

Il design del vessel in acciaio e’ stato realizzato dal nostro CAD partendo dal disegno di un oggetto simile realizzato dai colleghi con cui collaboriamo in AIDAInnova. Contiamo di farlo realizzare da una ditta esterna dato che in particolare per il cilindro sono necessarie attrezzature che non abbiamo in sezione. Il disegno e le caratteristiche richieste sono state definite; stiamo al momento effettuando una ricerca per individuare possibili ditte produttrici. Con 50cm di deriva e circa 30-40cm di diametro, una volta realizzato il prototipo sara’ il piu’ grande di questo tipo e potra’ essere utilizzato anche su fascio oltre che per misure in laboratorio.



Su queste attivita’ ci sono stati accordati sui servizi 1 MU di officina meccanica e 1,5 MU di progettazione meccanica come AIDAInnova per il 2024

Piano Pluriennale di spesa

YEAR	Item	Cost (Keuro)	Total/Year	Comment
2024	Vessel (10Bar)	22	62	DRD1,W8
	Flow Meters	19		DRD1,W8,W4
	HV (100KV)	21		DRD1,W8
2025	Recirculation and purification system for gasses which are expensive or sensitive to trace impurities (Ne is particularly expensive)	12	17	DRD1,W8,W4
	SiPm array for optical readout	5		DRD1,W8,W4
2026	TimePiX4 + optical interface	18	18	DRD1,W8,W4
Total			**97**	

* Non sono inclusi eventuali consumi e piccole spese per test-beam 2025/26