Why a TPC as a muon monitor in the cooling sector

- Full particle parameters (x, p) reconstructed in 3D
- Very low material budget, excellent track resolution
- It was already in the MICE proposal, but it can now made much better with an optical readout
- It still requires studies to design and test the readout, and find the optimal gas mixture in optical mode

In 2023 the Bari group proposed to realize a large prototype of a TPC (30 cm diameter, 50 cm drift) with optical readout (TimePix4 or similar) tailored to precise, particle-by-particle muon emittance measurement during beam setup phases

- A field-cage suitable for atmospheric-pressure operation is already available.
- The readout part can be easily replaced with an optical one.
- Once ready, the size allows to insert it in a solenoid (we know of one available at CERN) and test it in a muon beam.
- MPGD TPCs were already studied for beam monitoring, e.g. https://web2.infn.it/GEMINI/index.php/compact-tpc

- The optical readout has in this case the advantage to allow lighter structures and higher rate w.r.t. a traditional pad plane
- The development of this device may be synergic with the development of a TPC as an active target and both fit very well the **DRD1,W8/W4 Program**
- This application requires non-pressurized (or low pressurized) operation.

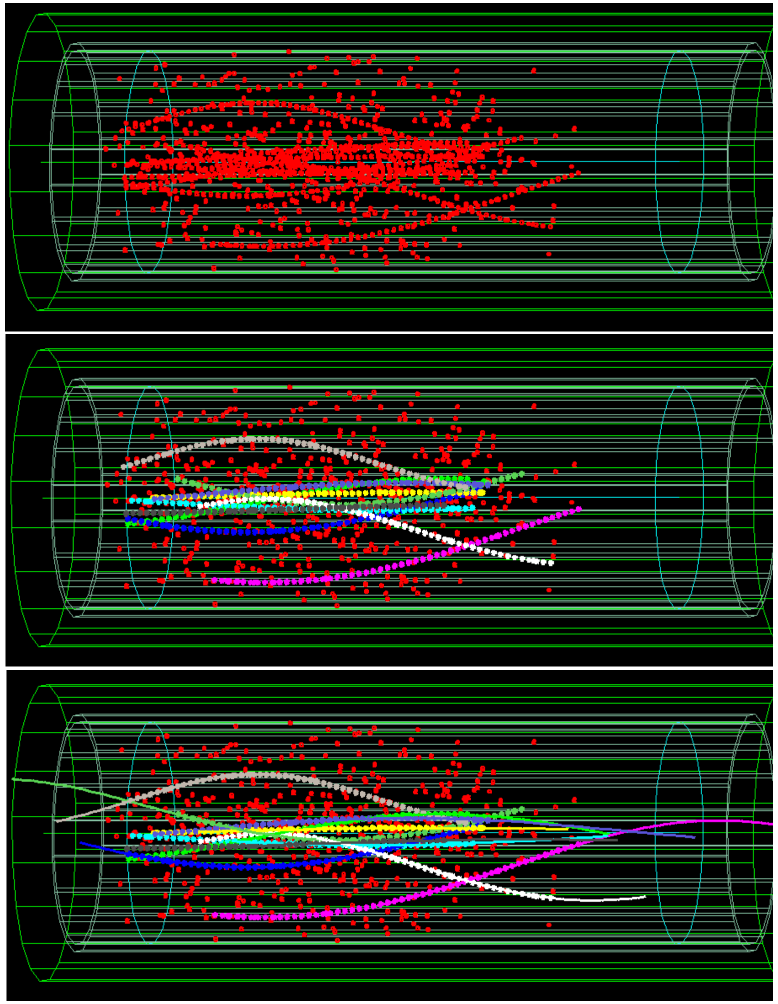


Figure 8.7: top: simulated track and noise hits in the TPG; middle: highlighted hits are those assigned by the pattern recognition to belong to the same track; bottom: track fitted on the selected hits

Status & Prospect of the TPC with optical readout project at INFN-Bari (AIDAInnova, MUCOL, DRD1/WP8/WP4)

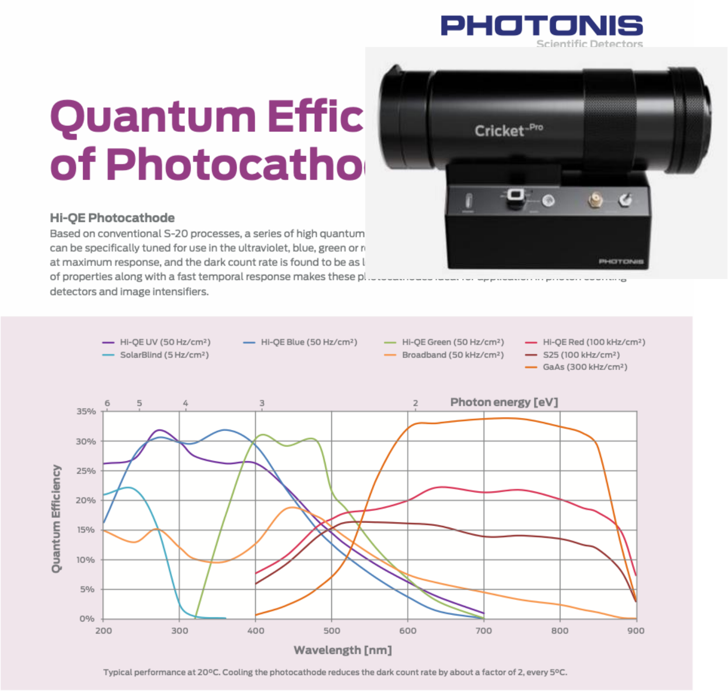
Basic idea of the project (AIDAInnova)
Development of an experimental setup similar in size to the UK one, enabling complementary measurements.

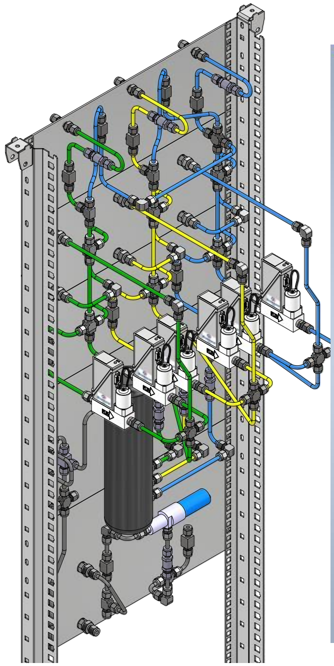
•Vessel modified at the flanges to allow flexibility in inputs and tightness in the range from 100–200 mbar up to 10 bar.
•Flexible gas system that allows the use of various gases (including light ones such as Helium) and the creation of ternary mixtures, as well as gas and impurity analysis.
•Image intensifier also sensitive to infrared photons.

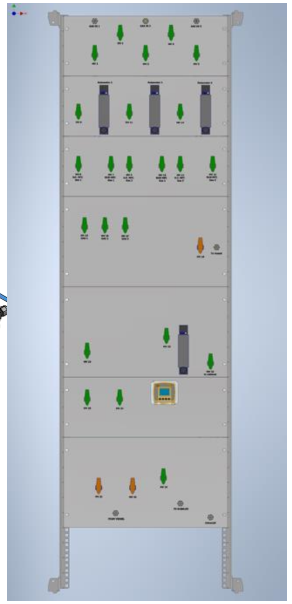
Status of the project

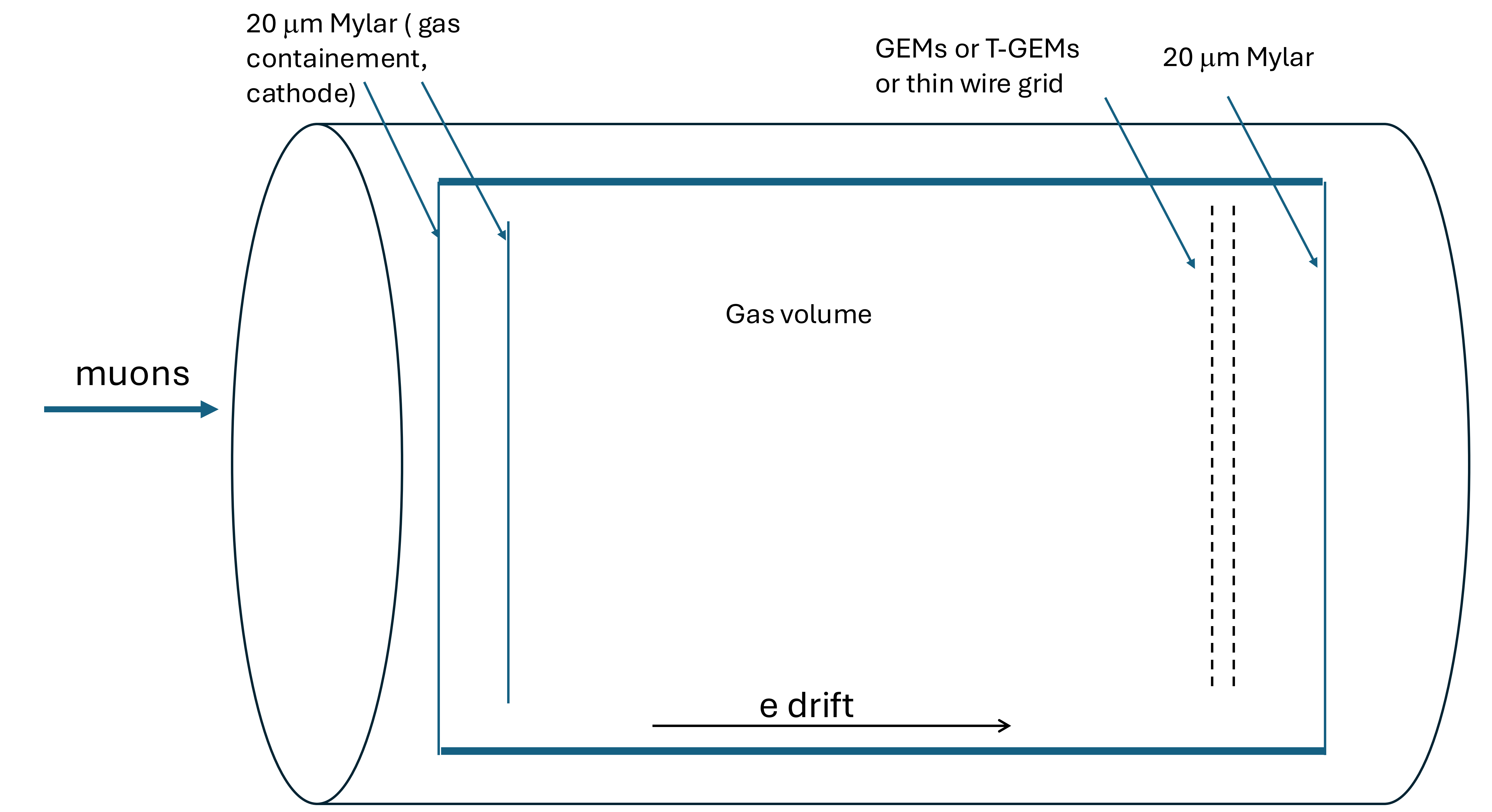
- Vessel , tables and support: realized & installed
- HV , LV electronics : procured
- Gas system:
    - procurement completed , items tested
    - in construction (ready summer 2025)
- Image intensifier : procured
- Thick gems : designed ready to be procured
- FieldCage : Design baseline (OK)
- TimePIX3: borrowed

New:
Test a TPC with optical readout in the range 100-200 mbar to be used as very light muon monitor in the demonstrator







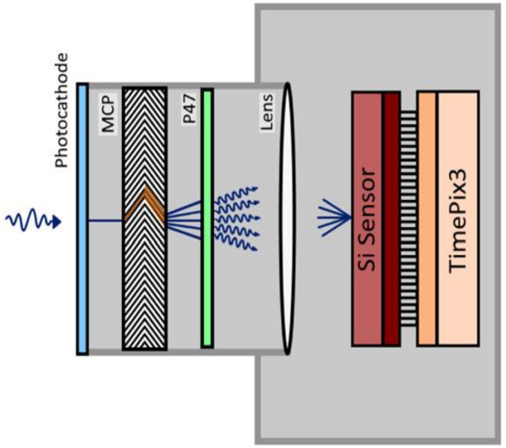

20 μm Mylar (gas containement, cathode)
GEMs or T-GEMs or thin wire grid
20 μm Mylar
Gas volume
muons
e drift

Perché indagare anche P < 1atm

- Una TPC offre la possibilità di registrare un numero molto grande di coordinate lungo un'elica, con un numero di X_0 minimo
- Ridurre la pressione ha come effetto di
  - Ridurre la quantità di materiale sul fascio (a 100 mbar il gas diventa sostanzialmente irrilevante nel calcolo di X_0 totali)
  - Aumentare la velocità di deriva (e quindi la tolleranza a un alto numero di tracce)
- La disponibilità di un vessel pressurizzato permette di lavorare anche in de-pressione tramite una procedura semplice:
  - Evacuare il volume con una pompa, con un leggero bakeout (non c'è bisogno di alto vuoto)
  - Riempire in modo statico fino alla pressione scelta con la miscela di gas
- Miscele con CF_4 (anche puro) sono buone candidate da cui partire, ed emettono nel rosso con un buon match con l'intensificatore d'immagine disponibile.

Status & Prospect

- A **Settembre 2023** , **l'R&D riguardante lo sviluppo di una TPC con read-out ottico nell'ambito di RD_MUCOL e' stato approvato dalla CSN1.**
- Sono stati finanziati (o sono in fase di finanziamento) solo items riguardanti la versione non-pressurizzata del detector.
- Le restanti richieste (benche' approvate scientificamente) sono stato rimandate alla discussione riguardante i finanziamenti specifici dei DRD .
- Nel **2024** e' stato finanziato il sistema della alte tensioni da 100KV per **21Keuro.**
- Nel **2025** e' stato finanziato *l'image Intensifier* **(28Keuro)** ma non i 2 piani di thick gem (30 cm di diametro) e l' obiettivo fotografico che fanno parte del sistema di intensificazione del segnale ottico.
- I due items sono stati rimandati al finanziamento dei DRD (mai avvenuto), ma sono essenziali per mettere in funzione il readout.
- Nel **2026 chiediamo gli elementi mancanti della catena di readout e cavi e connettori HV in modo da mettere in funzione il prototipo e una field cage da utilizzare all'interno del vessel per l'utilizzo nel range 100-200 mbar (NEW).**
- Per quanto riguarda il **TimePix** il cui acquisto era previsto nel **2026** preferiamo rimandarlo e utilizzare inizialmente il TimePix3 che possiamo avere in prestito dai colleghi inglesi. Ci sono infatti ancora difficolta' a capire il costo e i tempi necessari per otteneme uno.



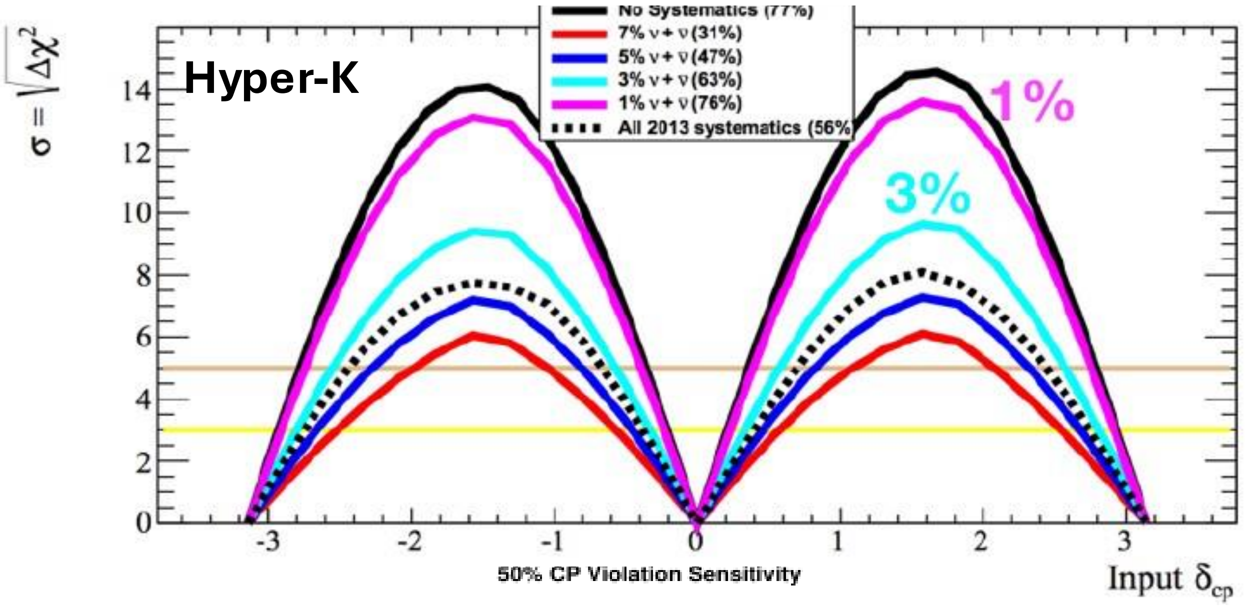
Catena di Read-out

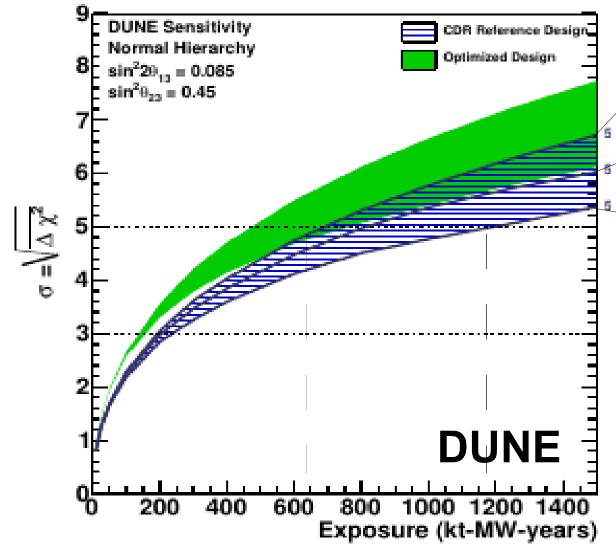

Esempio di piano di Thick gem

Richieste 2026 (e finanziamenti degli anni precedenti)

YEAR	Item	Cost (Keuro)	Total/Year (investment)	Possible connection & synergy with DRD1
2024	HV (100KV)	21	21	WP4 ,WP8
2025	Image Intensifier	21	29	WP4, WP8
	trasporti	1		
2026	2 Thick Gems	5	25	WP8, WP4
	Obiettivo Fotografico	5		
	Pompa Rotativa +Fasce Scaldanti **(under pression)**	3+1		
	Field Cage (kapton strip foil) **(under pression)**	5		
	HV Cables and connectors	3		
	mechanical supports	3		

Sensitivity of future Neutrino Oscillation Experiments





5% ± 1%

5% ± 2%

5% ± 3%

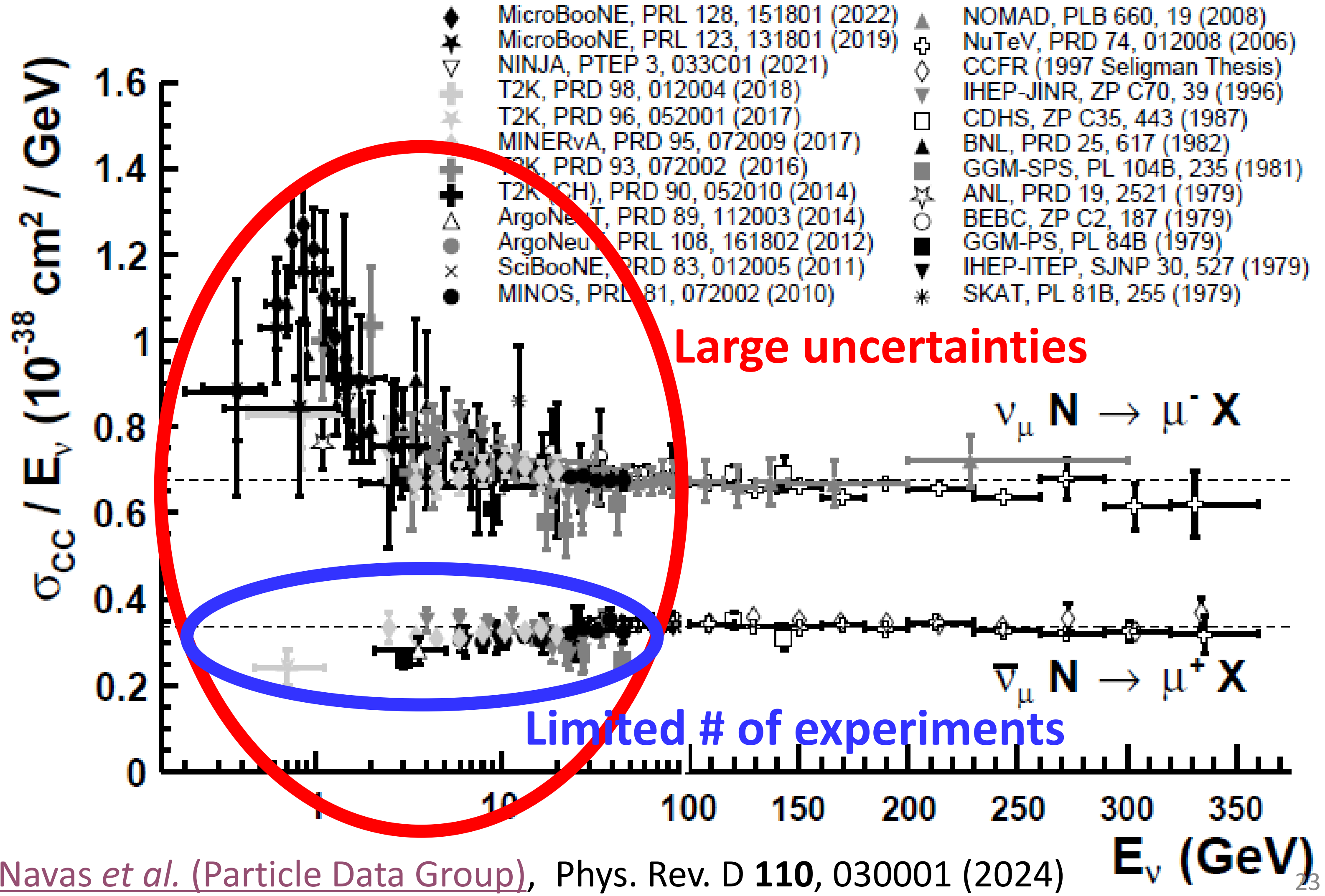
→ equivalen
to factor 2 in
exposure!

- *Up to now the precision was limited by statistics but once DUNE and Hyper-Kamiokande will begin data collection, their unprecedented beam power and large detector mass will drastically reduce statistical uncertainties, making systematic errors the dominant constraint on their physics potential.*
- The sensitivity of future neutrino oscillation experiments strongly depends on the ability to reduce the impact of systematic errors to the percent level.
- Uncertainties in low-energy cross-section measurements (0.2–5 GeV/c) and Monte Carlo models affect the extrapolation of fluxes from Near Detectors (ND) to Far Detectors (FD), limiting the precision of the results.

Current status of “neutrino cross-section” measurements

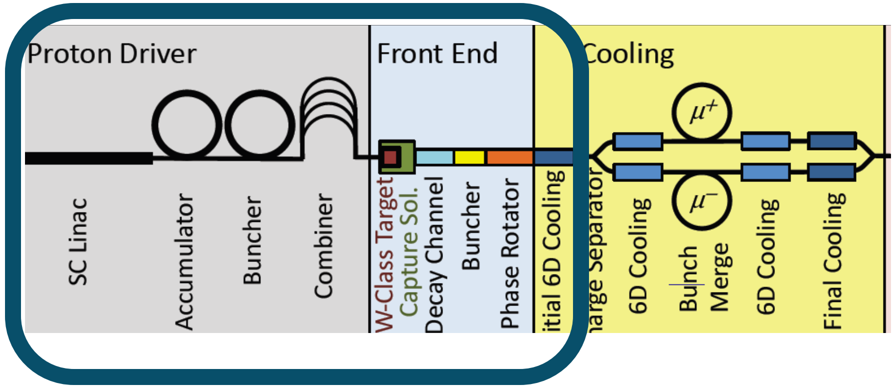
Inclusive charged current total cross-section

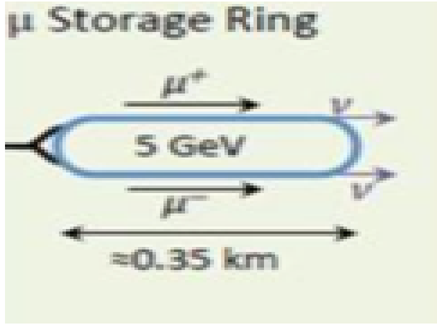
(G.P. Zeller’s review)



S. Navas *et al.* (Particle Data Group), Phys. Rev. D **110**, 030001 (2024)

A Low energy Neutrino beam as first stage of a muon collider (European Strategy contribution, article in preparation)





$$+ \quad \mu^{+} \rightarrow e^{+} \nu_e \bar{\nu}_\mu$$

$$\mu^{-} \rightarrow e^{-} \bar{\nu}_e \nu_\mu$$

First intense ν_e and $\bar{\nu}_e$ Beam in the word !!

- *neutrino beams via muon decay in the straight section of a storage ring.*
- Key advantages of generating neutrino beams from muon decays rather than meson decays are:
  - The absolute neutrino flux can be accurately determined, provided the stored muon current, momentum, and polarization are carefully measured.
  - The beam contains only one type of neutrino and one type of antineutrino, with their identities controllable by selecting the charge of the stored muons.
  - This enables precise measurements of ν_e, ν_μ, (anti)ν_e, and (anti) ν_μ.

Physics Motivation:

- Neutrino X-sections measurements in this range are very few, old and show large discrepancies
- The lack of those information can bias or reduce the sensibility of the future generation Neutrino Oscillation experiments

https://indico.cern.ch/event/1439855/contributions/6461652/