Developing gaseous detectors at IGFAE

Diego Gonzalez Diaz

20/12/2017

reference materials

Detectors and concepts for sub-100ps timing with gaseous detectors
DG-D et al. JINST 12(2017), 3, C03029

Secondary scintillation yield of xenon with sub-percent levels of CO_2 additive for rare-event detection
C. A. O. Henriques, E.D.C. Freitas, C.D.R. Azevedo, **DG-D** et al., Phys. Lett. B773 (2017) 663-671

Microscopic simulation of xenon-based optical TPCs in the presence of molecular additives
C. D. R. Azevedo, **DG-D** et al., Nucl. Instrum. Meth. A877 (2018) 157-172

Gaseous and dual-phase time projection chambers for imaging rare processes
DG-D et al., Nucl. Instrum. Meth. A878 (2018) 200-255

Helium-Xenon mixtures to improve the topological signature in high pressure gas xenon TPCs
R. Felkai, F. Monrabal, **DG-D** et al., arXiv:1710.05600

PICOSEC: charge particle timing at sub-25ps precision with a Micromegas based detector
J. Bortfeld et al., arXiv:1712.05256

strong unofficial support by LabCAF (J. A. Garzón)!

contributing people (non-seniors)

Manuel Fontaíña (grad student)
Damián García (PhD student)
David Gonzalez (technologist)
Marwan Ajoor (master student)

and undergrad students (tfg)

Mateo Torreiro
Irene Ball

projects and funding

RyC program

Xunta (proxectos de excelencia), PI: with J. A. Hernando, C. Adam,
Development of time projection chambers with optical readout (OTPCs) for neutrino physics and other strange processes

RD51-CERN common projects, PI with E. Baracchini (INFN) and 6 Institutes,
New scintillating gases and structures for next-generation scintillation-based gaseous detectors

Xunta (grupos de referencia competitiva), PI: J. Benlliure

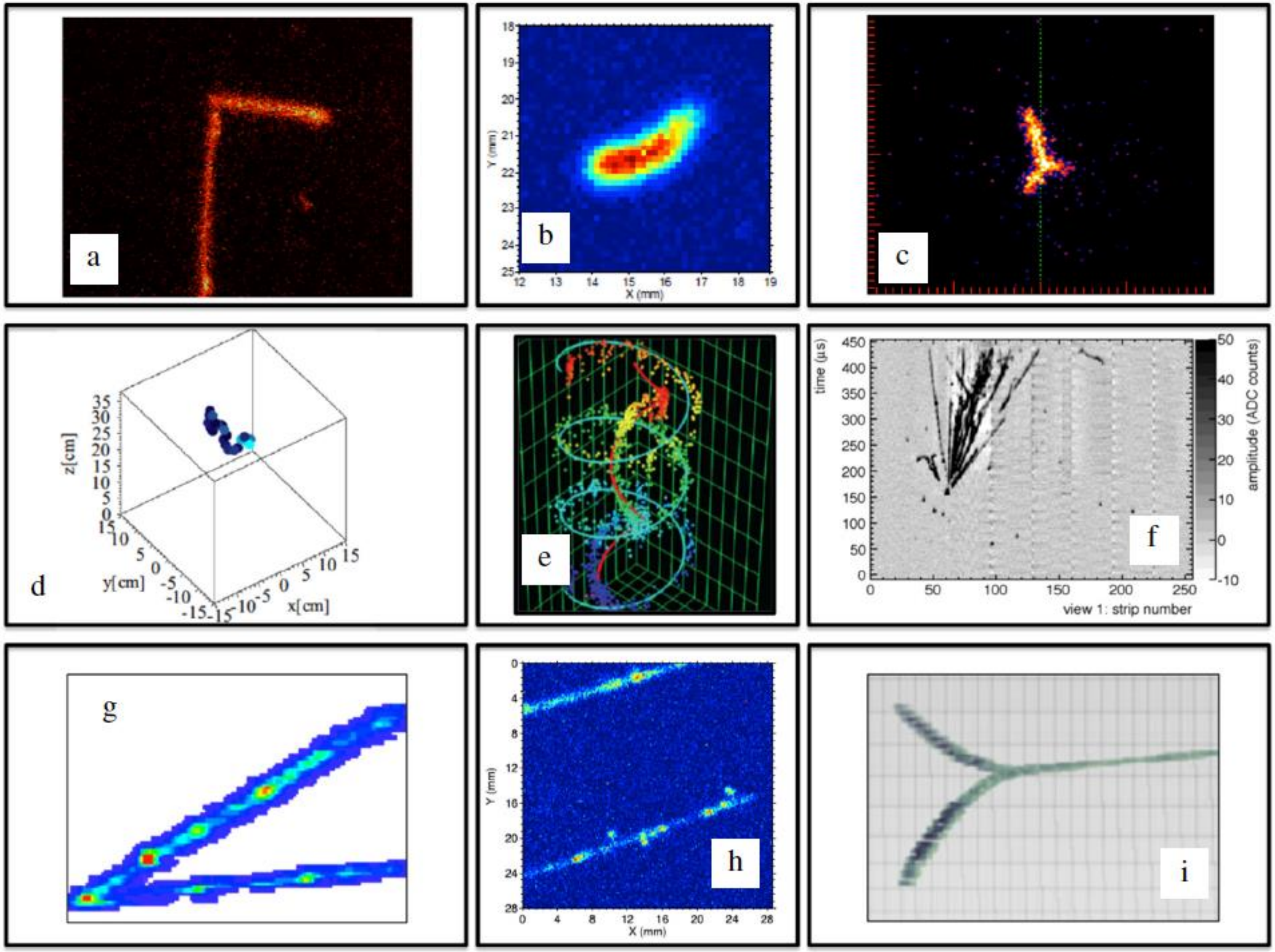
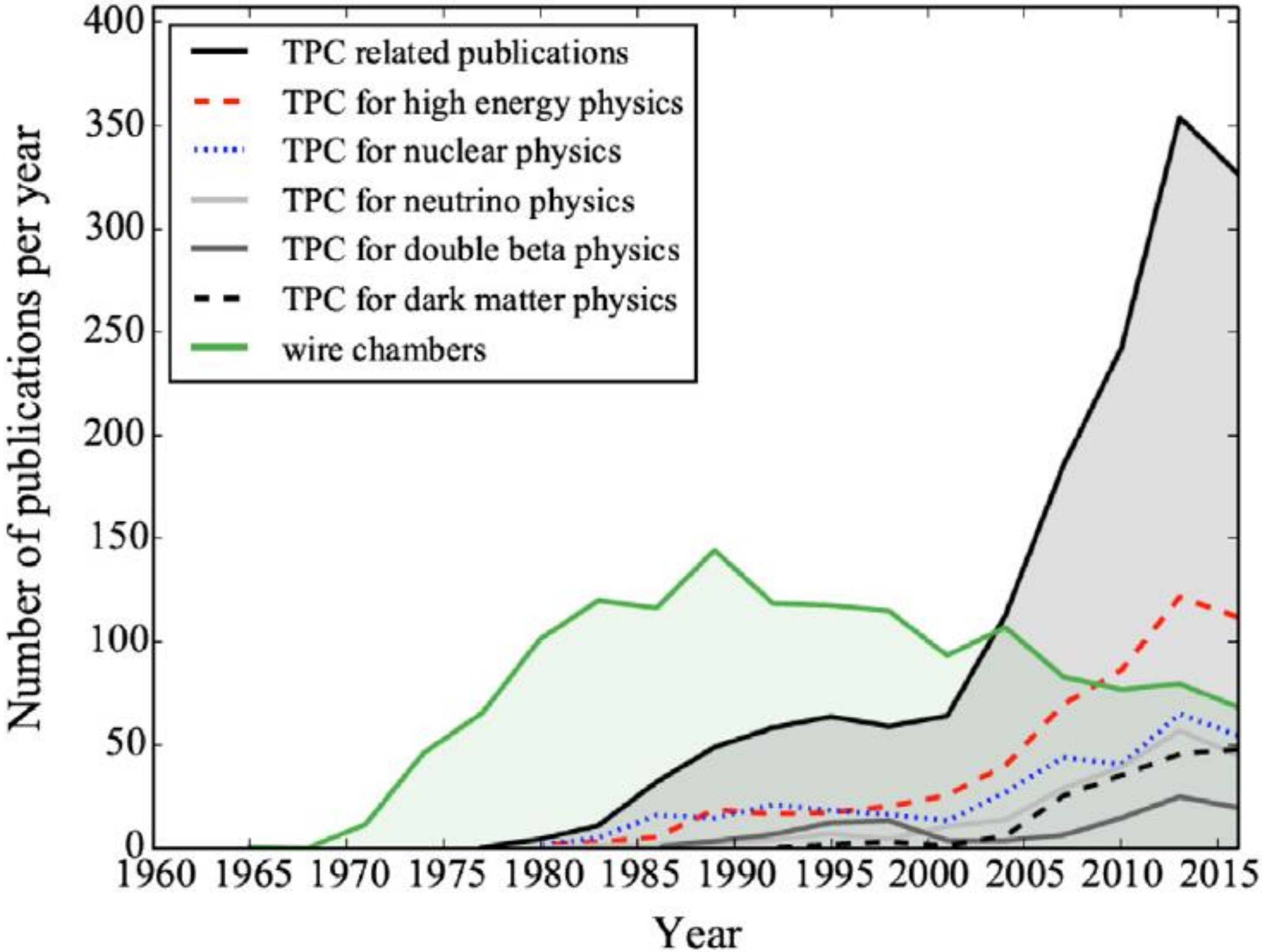


Fig. 3. Some representative images obtained with state of the art TPCs employed outside collider physics: a) β-delayed proton emission from ^{46}Fe [76]; b) a low energy C or F nucleus ($\varepsilon = 214\,\mathrm{keV}$) recoiling against a neutron [11]; c) a triple α event produced after the reaction $^{12}\mathrm{C}(\gamma,\alpha)^{8}\mathrm{Be}$ in a 150 mbar CO_2/N_2 active target [15]; d) a 1.275 MeV photoelectron from a ^{22}Na source in a 10 bar xenon/TMA admixture [36]; e) a low energy electron spiraling in a magnetic field, reconstructed in a $\sim 1\,\mathrm{cm}^3$ mini-TPC with an InGrid device [10]; f) a cosmic ray shower obtained with the dual-phase argon TPC of the WA105 collaboration [9]; g) pair production of a 74.3 GeV photon in the HARPO polarimeter, based on pressurized argon [77]; h) electrons with energies above 30 keV, reconstructed in 50 mbar of CF_4; i) elastic scattering between two α-particles at around 1 bar, reconstructed with the AT-TPC [78].

TPC: time projection chamber



from scopus (efficiency and purity of selections verified to be within 85%)

ALICE
(heavy ion reactions)

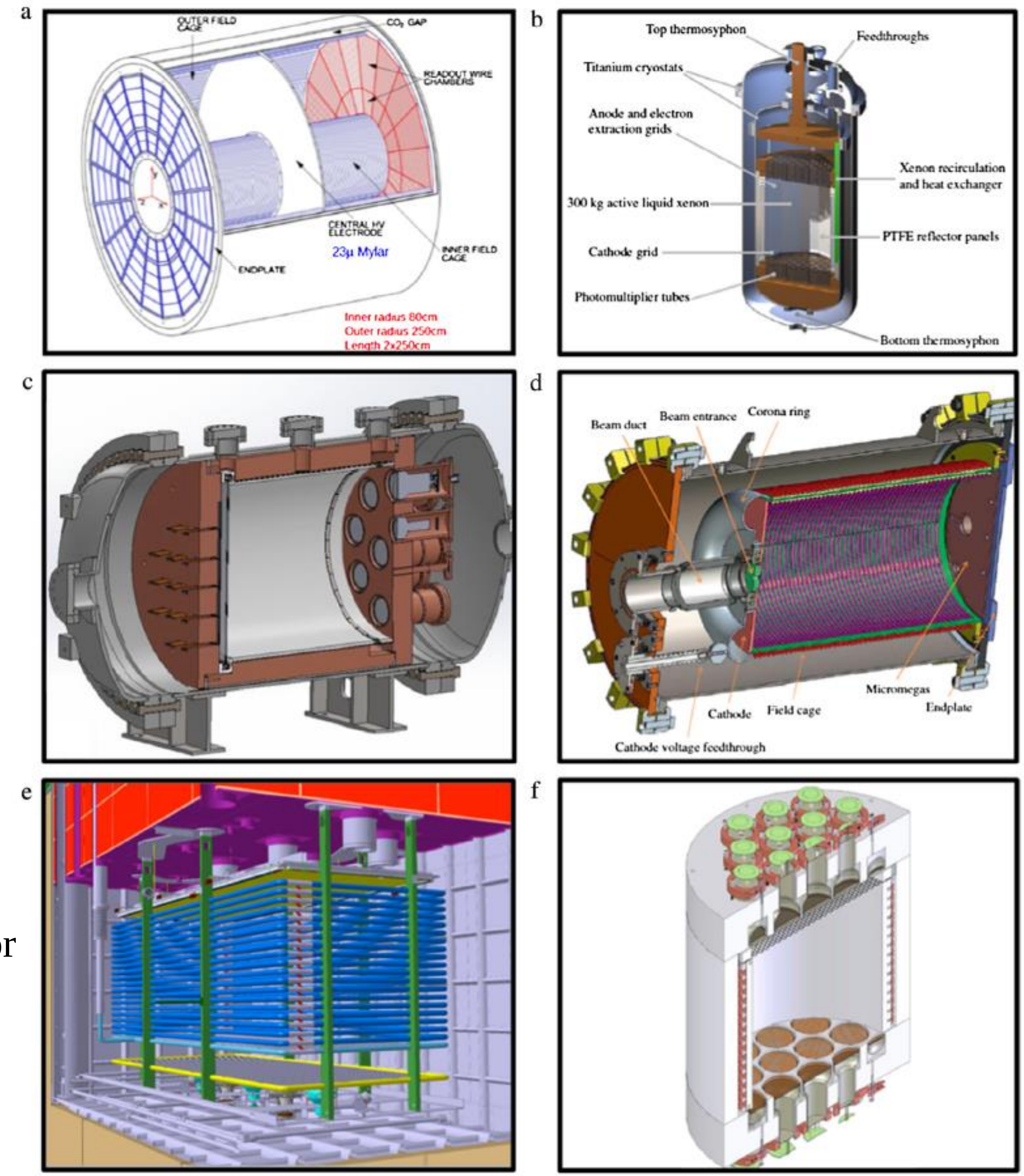
LUX
(Dark Matter)

NEXT-NEW
($\beta\beta$0-decay)

AT-TPC
(nuclear physics)

DUNE Far Detector
(neutrino oscillations)

DarkSide-50
(Dark Matter)

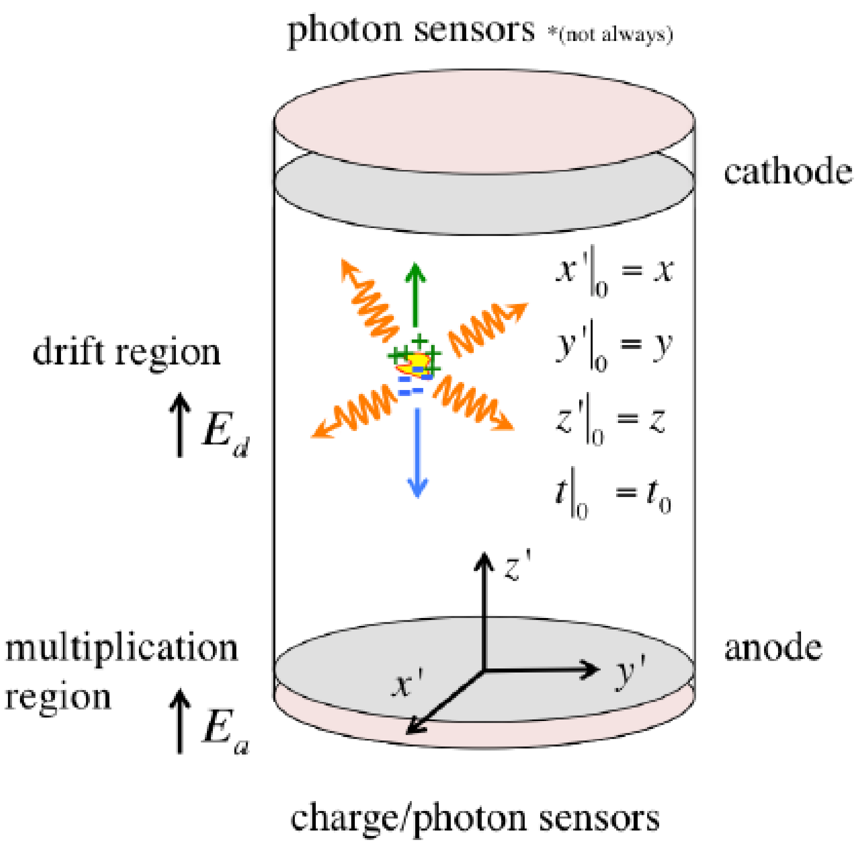


TPC	E_d [V/cm]	B [T]	$H(\times S)$ [m × m^2]	P [bar]	image plane	layout	medium	Ref
ACTAR	flexible	-	$0.25\,(\times 0.25^2)$	0.1-3	MM (bulk)	3D	generic (H_2, He, Ar...)	[16]
AT-TPC	flexible	up to 2	$1\,(\times\pi\, 0.3^2)$	0.05-1	MM (microbulk)	3D	generic (H_2, He, Ar, CO_2...)	[78]
Warsaw	flexible	-	$0.21\,(\times 0.18 \times 31)$	1	4-GEM + PMT + CCD	2D+1D	Ar/He/CH_4/N_2-based	[76]
TUNL	flexible	-	$0.21\,(\times 0.3 \times 0.3)$	0.13-0.18	MSAC + PMTs + CCD	2D+1D	CO_2/N_2	[15]
NEXT-NEW	200-600	-	$0.53\,(\times\pi\, 0.21^2)$	5-15	mesh + SiPMs + PMTs	3D	^{136}Xe-enriched xenon	-
PandaX-III	up to 1000	-	$(2\times)\,1\,(\times\pi\, 0.75^2)$	10	MM (microbulk)	2D+2D	^{136}Xe-enriched Xe/TMA	[287]
DRIFT	600-700	-	$(2\times)\,0.5\,(\times 1 \times 1)$	0.055	MWPC	2D+2D	CS_2,O_2-based	[39]
DMTPC	150-250	-	$(4\times)\,0.275\,(\times 1 \times 1)$	0.04-0.1	mesh + PMTs + CCDs	2D+1D	CF_4	[53,51]
NEWAGE	80-300	-	$0.41\,(\times 0.3 \times 0.3)$	0.2	μ-PIC + GEM	2D+2D	CF_4	[52]
MIMAC	100	-	$(2\times)\,0.25\,(\times 0.1 \times 0.1)$	0.05	MM (bulk)	2D+2D	$CF_4/CHF_3/i\text{-}C_4H_{10}$	[288,51]
TREX-DM	flexible	-	$(2\times)\,0.25\,(\times 0.25 \times 0.25)$	1-10	MM (microbulk)	2D+2D	Ne, Ar -based	[21]
T2K-ND	200-300	0.18	$(2\times)\,1.25\,(\times 1 \times 2.55)$	1	MM (bulk)	3D	$Ar/CF_4/i\text{-}C_4H_{10}$	[161]
CAST	$\sim$100	-	$0.03\,(\times 0.06 \times 0.06)$	1.4	MM (microbulk), INGRID	2D+2D	$Ar/i\text{-}C_4H_{10}$	[21,289]
MuCap	2000	-	$0.12\,(\times 0.15 \times 0.3)$	10	MWPC	2D+2D	D-depleted H_2	[290]
DUNE-FD	1000	-	$(\times 4)\,12\,(\times 60 \times 12)$	1	LEMs + PMTs	2D+2D	argon	[155]
LUX	181	-	$0.48\,(\times\pi\, 0.235^2)$	1-2	mesh + 2 PMT planes	3D	xenon	[291]
XENON1T	120	-	$1\,(\times\pi\, 0.5^2)$	1-2	mesh + 2 PMT planes	3D	xenon	[66]
PandaX-II	393.5	-	$0.6\,(\times\pi\, 0.32^2)$	1-2	mesh + 2 PMT planes	3D	xenon	[292]
DarkSide-50	200	-	$0.35\,(\times\pi\, 0.178^2)$	1	mesh + 2 PMT planes	3D	^{39}Ar-depleted argon	[43]
WARP(1001)	90-330	-	$0.6\,(\times\pi\, 0.25^2)$	1	mesh + PMTs	3D	argon	[293]
ALICE	400	0.5	$(2\times)\,2.5\,(\times 18)$	1	MWPC (GEMs)^{*a} + pads	3D	$Ne/CO_2/N_2$	[61]
STAR	135	0-0.5	$(2\times)\,2.1\,(\times 18)$	1	MWPC + pads	3D	Ar/CH_4	[286]

Table 5
Some technical parameters of the most representative TPCs used in the search of rare processes, both in gas (top block) and dual (middle block) phase. For reference, the lowest block includes two paradigmatic collider TPCs. The size of the active dimension along the electric field is dubbed H and S is the active area. For dual-phase, the electric field is given for the liquid phase and the pressure for the gas phase. The compilation is illustrative since several of the collaborations are already heading towards an upgrade, e.g., NEXT [182], MIMAC [51], T2K-ND [294], DarkSide [295] or LUX [23].

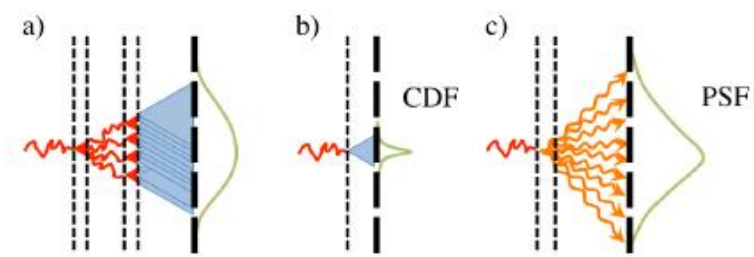
^{*a} the ALICE TPC will replace its MWPC plane by a 4-GEM one.

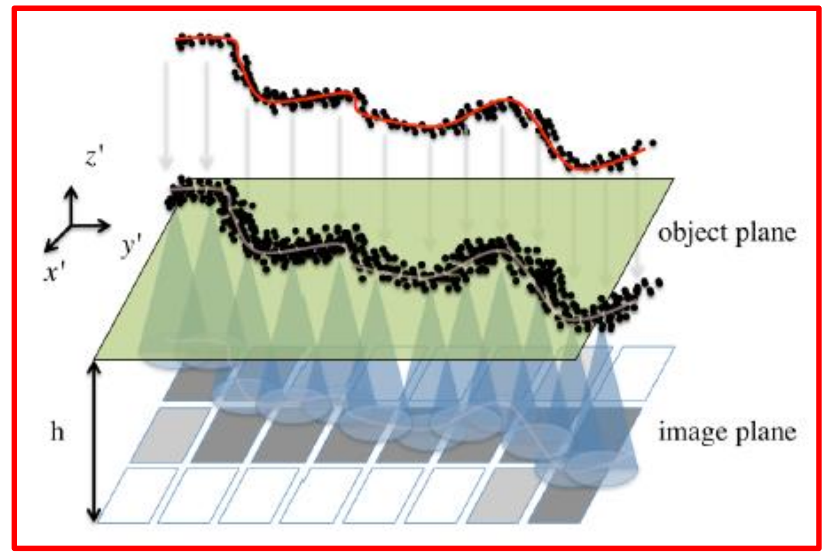
A generic TPC for rare event searches



- Aimed at complex topologies and maximal collection of event information.
- Seamless! (no beam pipe).
- Usually no space-charge issues.
- No ageing issues (interaction rate is low).
- Radiopurity issues (in some cases).
- B-field seldom found.

A generic image formation process in a TPC





point spread function

$$\delta(x'-x, y'-y) \rightarrow \mathcal{PSF}_{xy}(x'-x, y'-y)$$

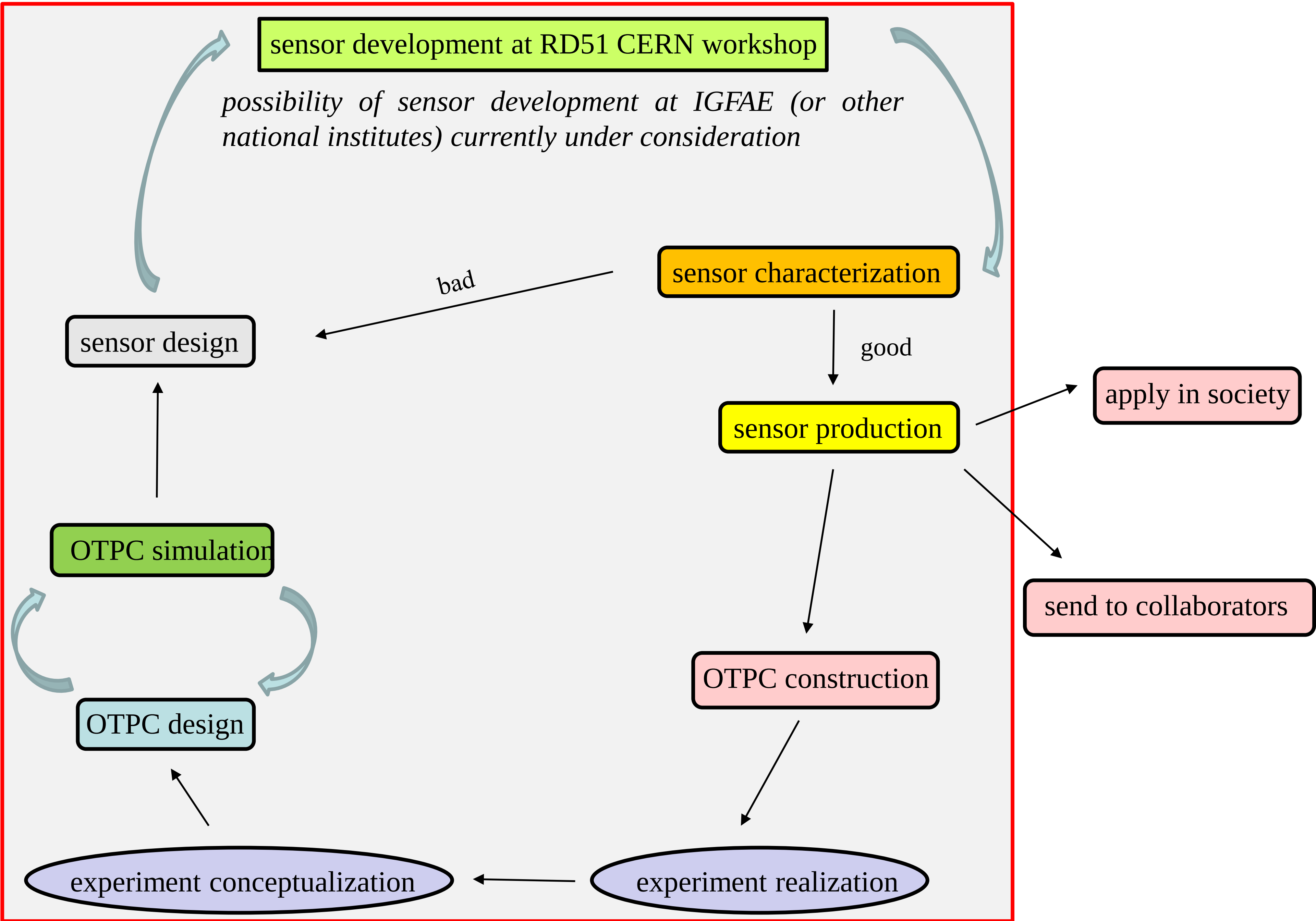
impulse response function

$$\delta(t-t_0) \rightarrow \mathcal{IRF}(t-t_0)$$

$$\sigma^{*,2}_{\mathcal{PSF}_{xy}} \simeq \sigma^2_{\mathcal{PSF}_{xy}} + D^{*,2}_T z$$

$$\sigma^{*,2}_{\mathcal{PSF}_z} \simeq v_d^2 \cdot \sigma^2_{\mathcal{IRF}} + D^{*,2}_L z$$

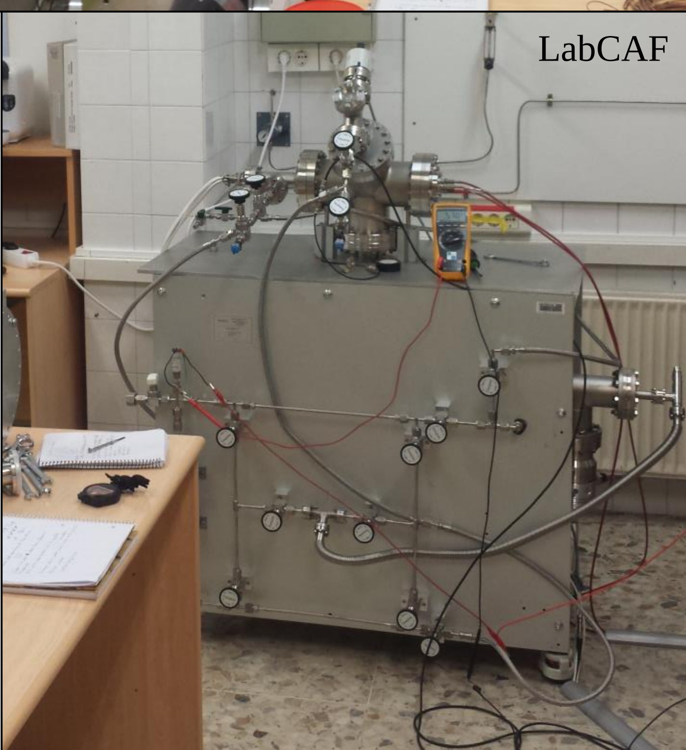
work flow



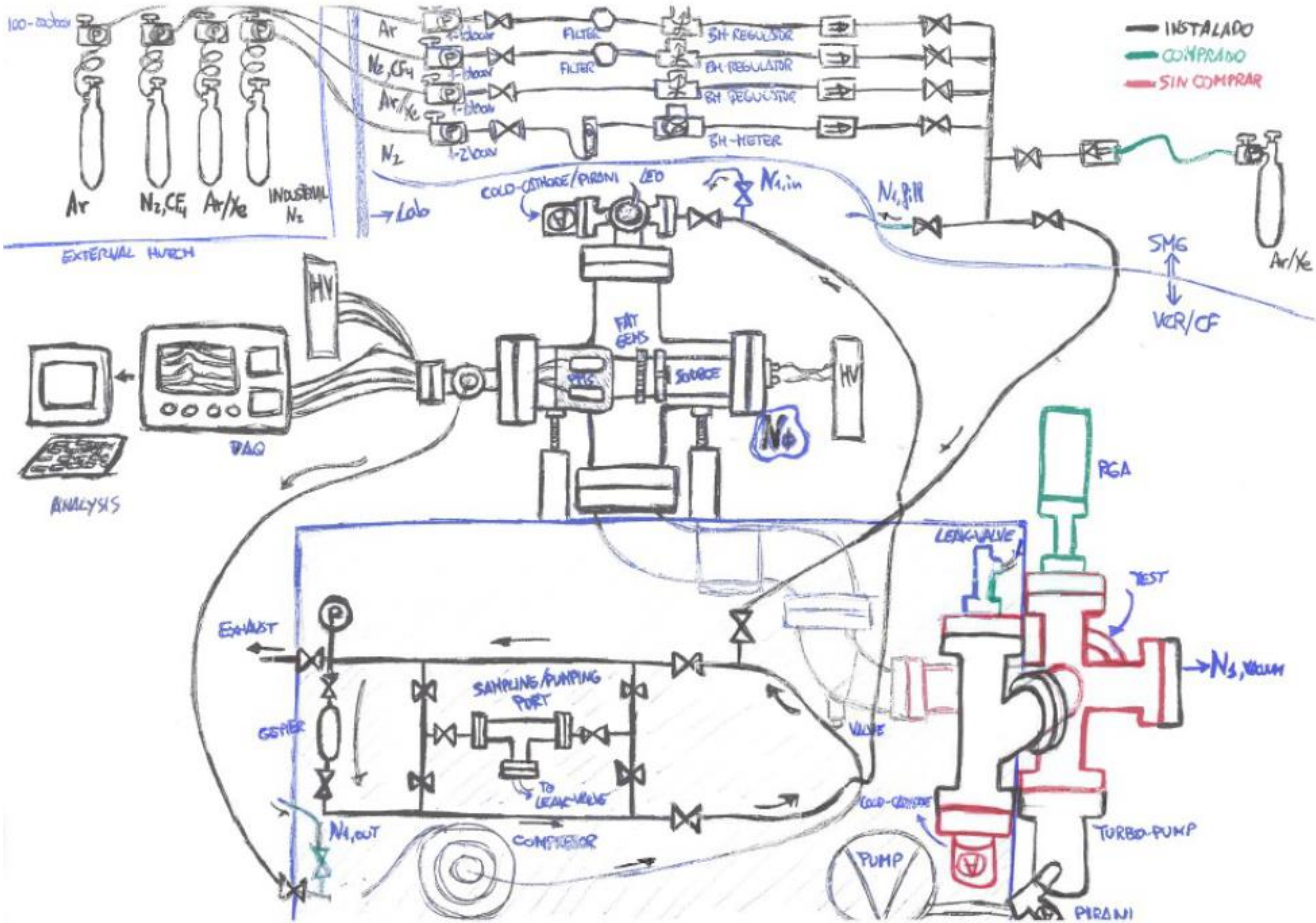
sensor development at RD51 CERN workshop
possibility of sensor development at IGFAE (or other national institutes) currently under consideration
sensor characterization
bad
good
sensor design
sensor production
apply in society
send to collaborators
OTPC simulation
OTPC construction
OTPC design
experiment conceptualization
experiment realization

why ‘Optical’ TPCs?

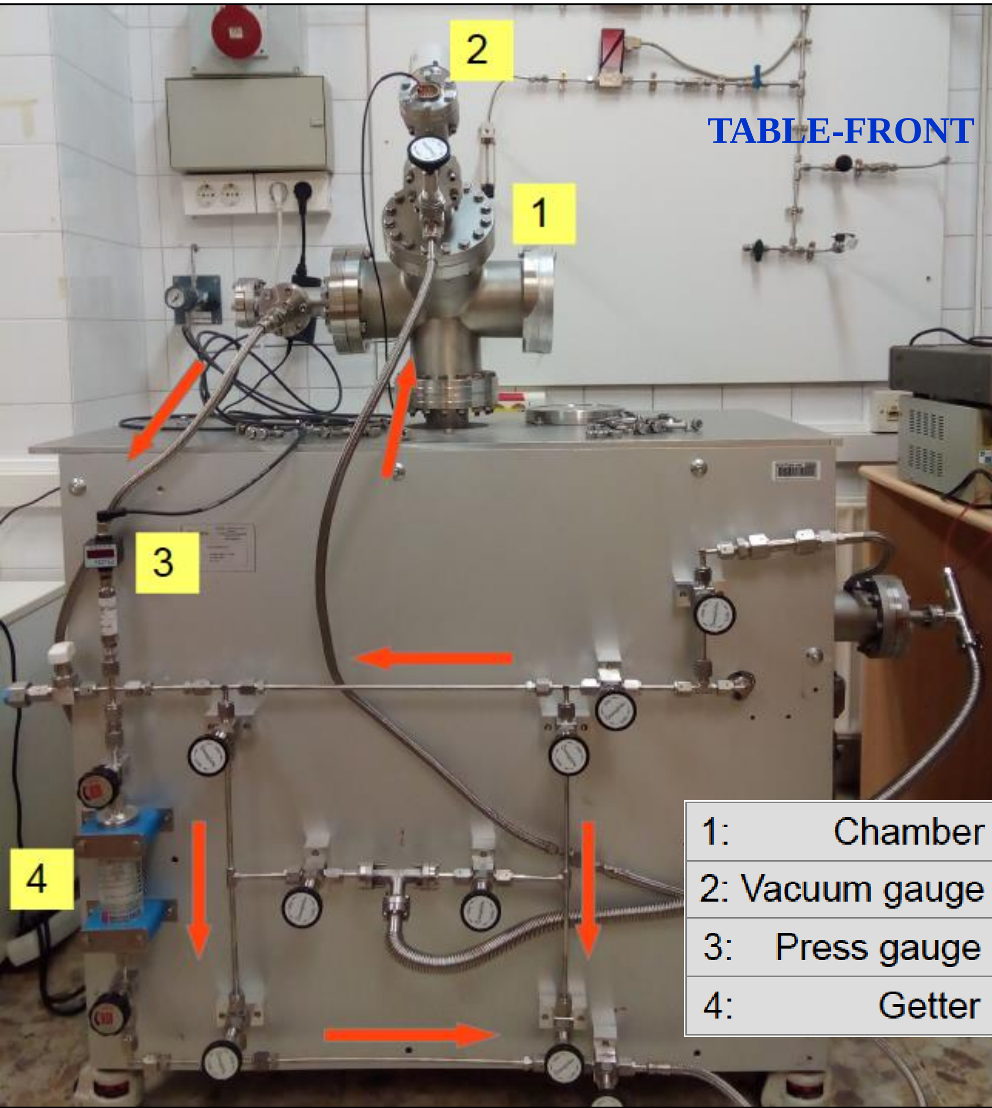
enabling assets I
(fully refurbished work space at LabCAF and workshop)

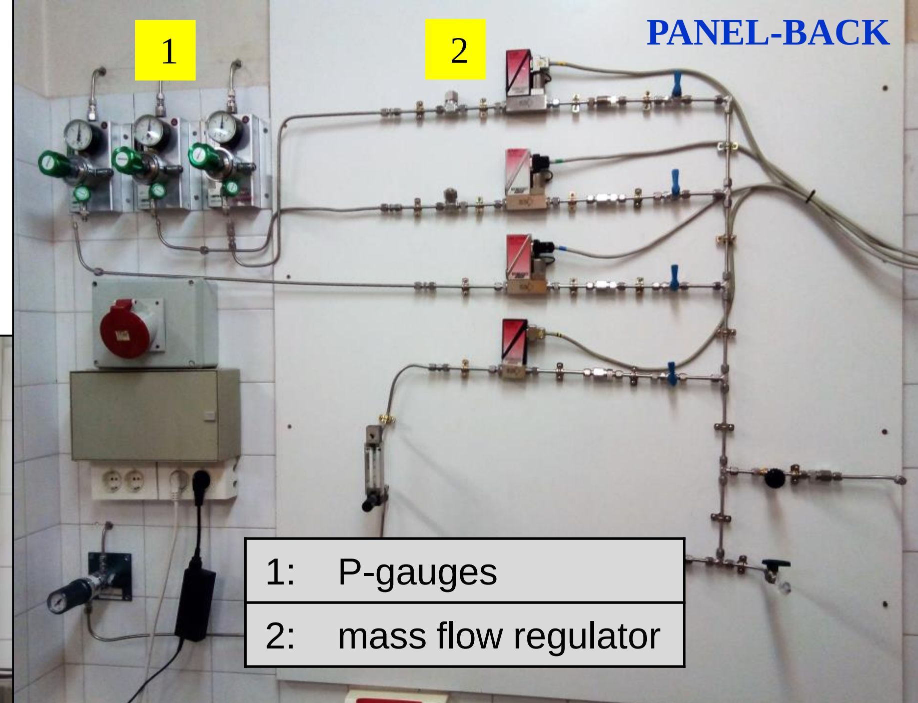


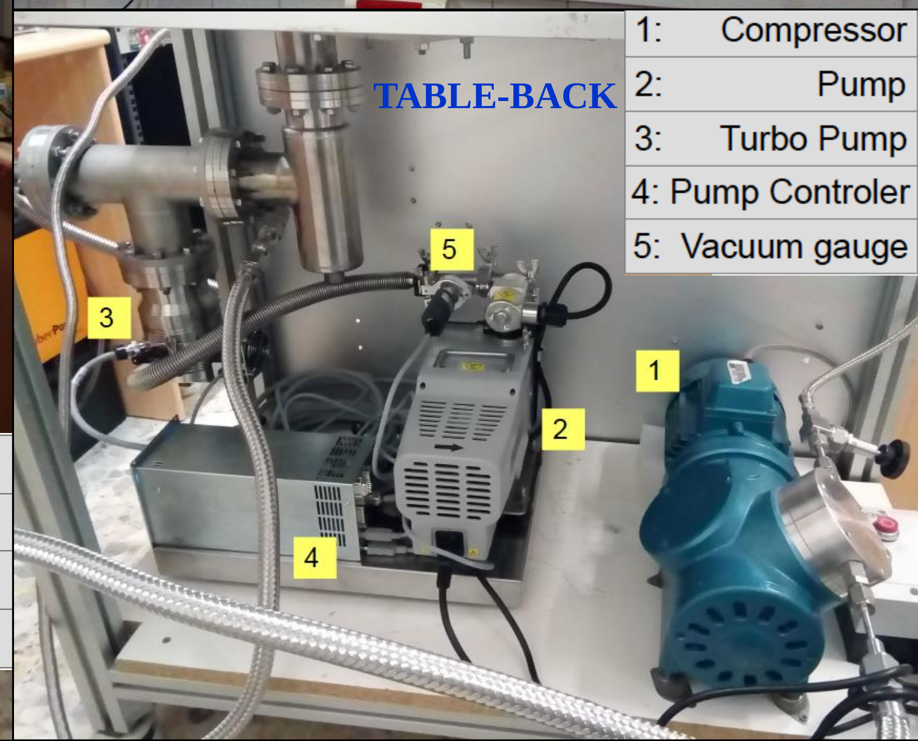
enabling assets II(a)
(gas, purification and vacuum system)



enabling assets II(b)
(gas, purification and vacuum system)

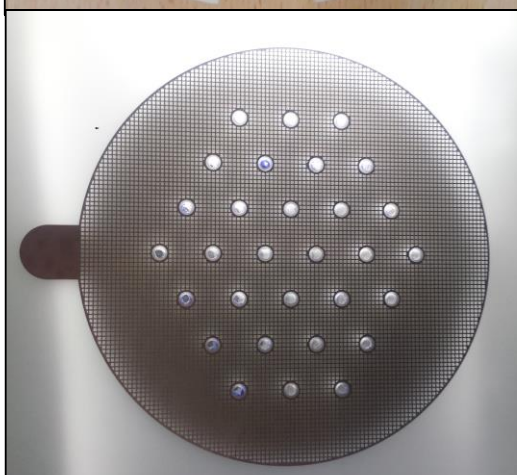


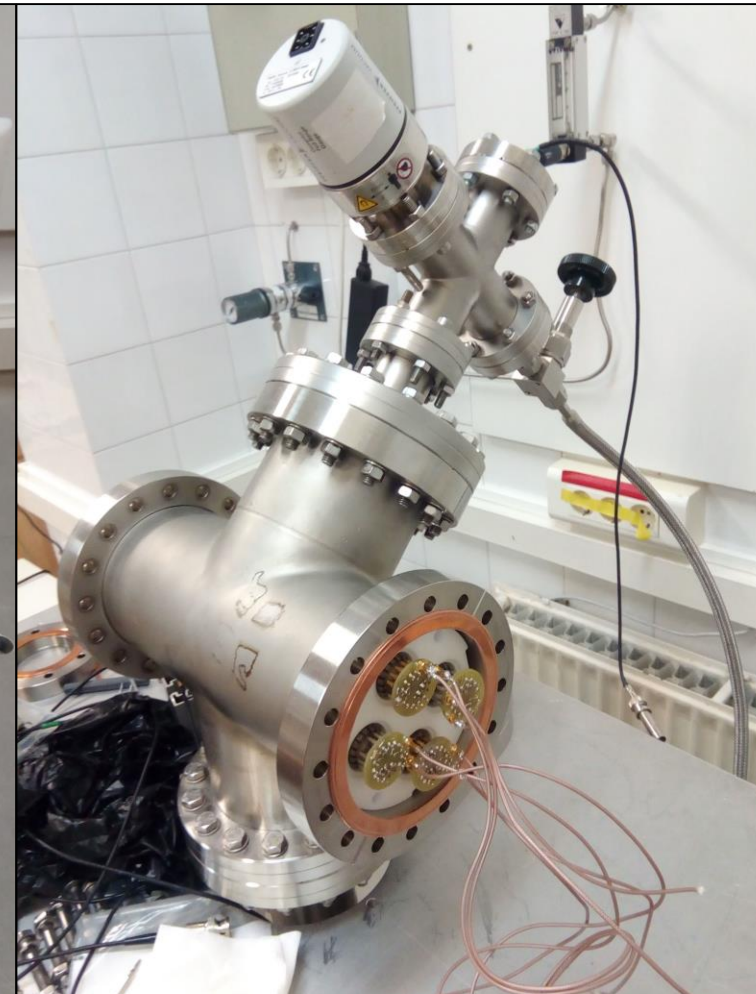




enabling assets III
(chamber for sensor characterization: Nausicaa0)

PMT teflon-frame



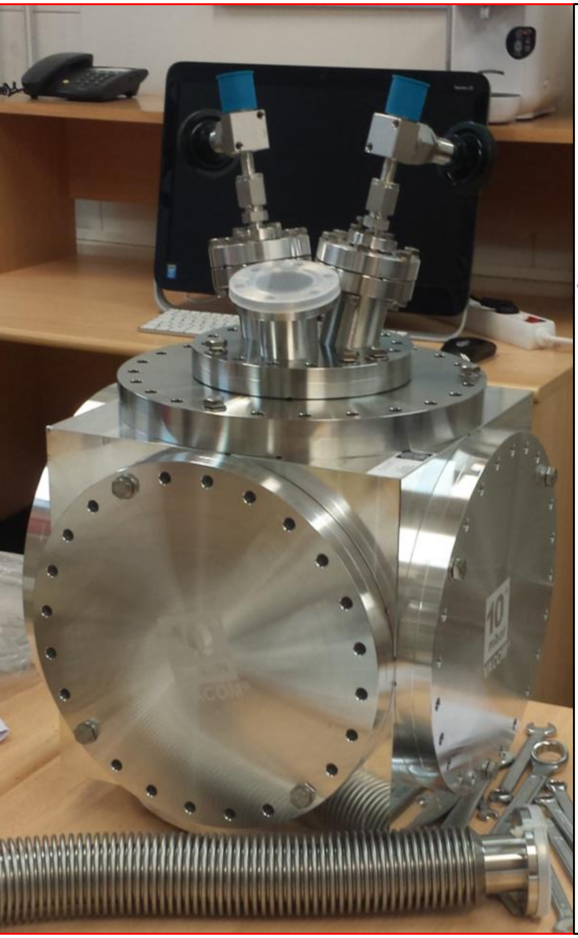


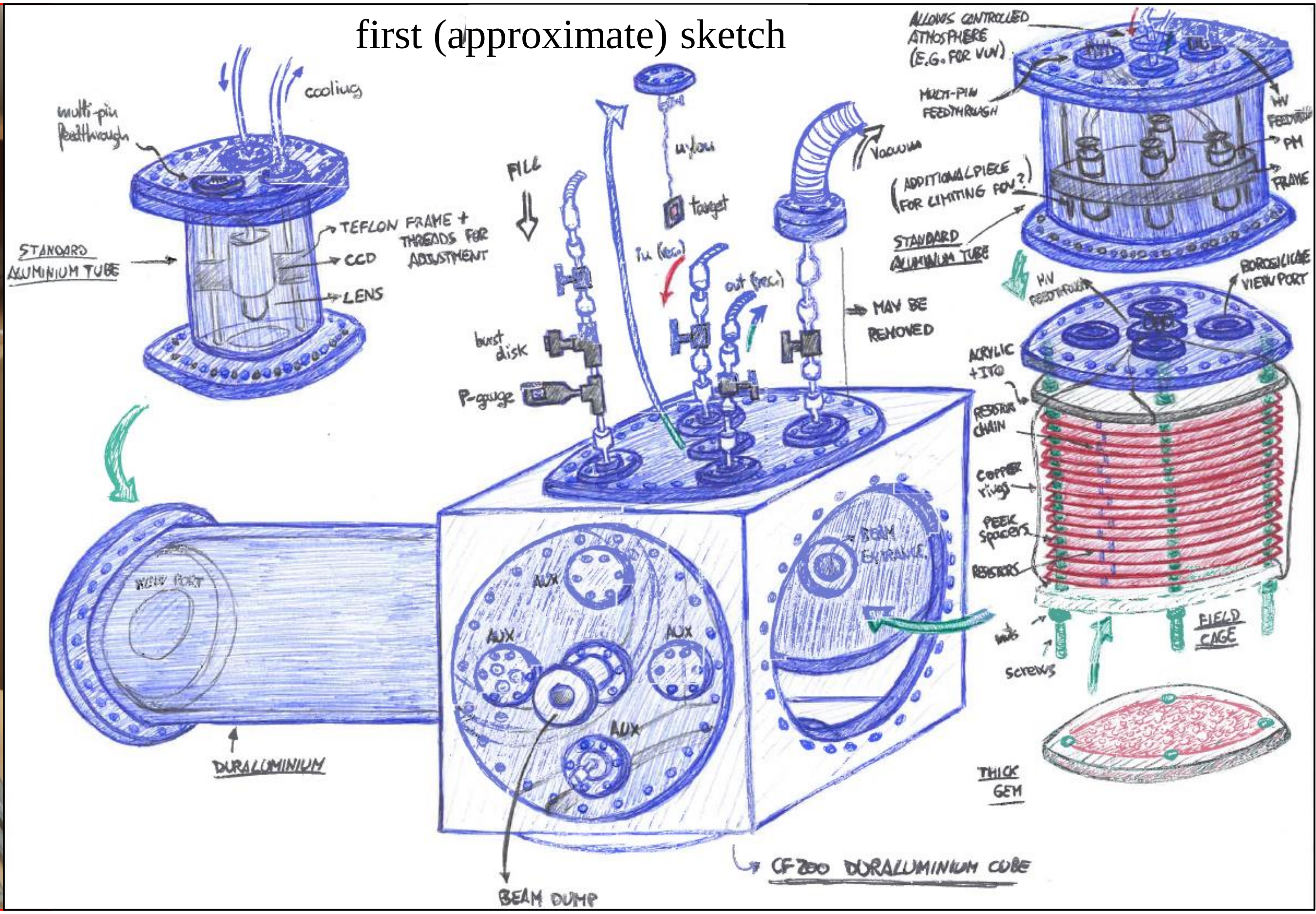
acrylic hole-based scintillator
(akin to GEMs, but x100 larger)

test assembly

Nausicaa0 general view

enabling assets IV
(chamber for experiments and commissioning of NEXT tiles: Nausicaa1)

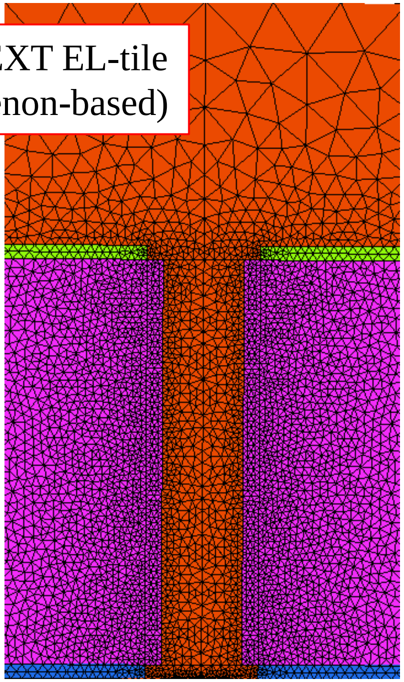


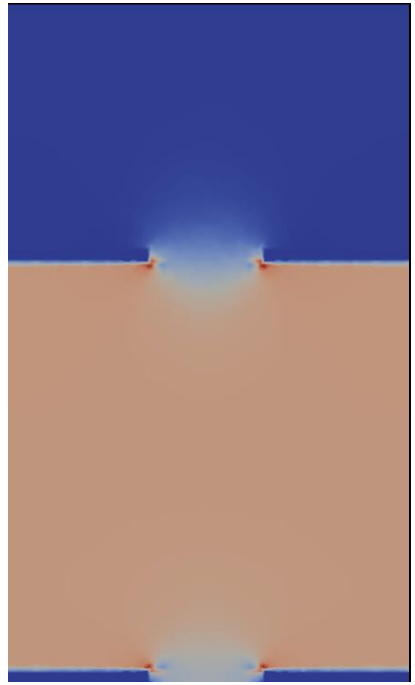


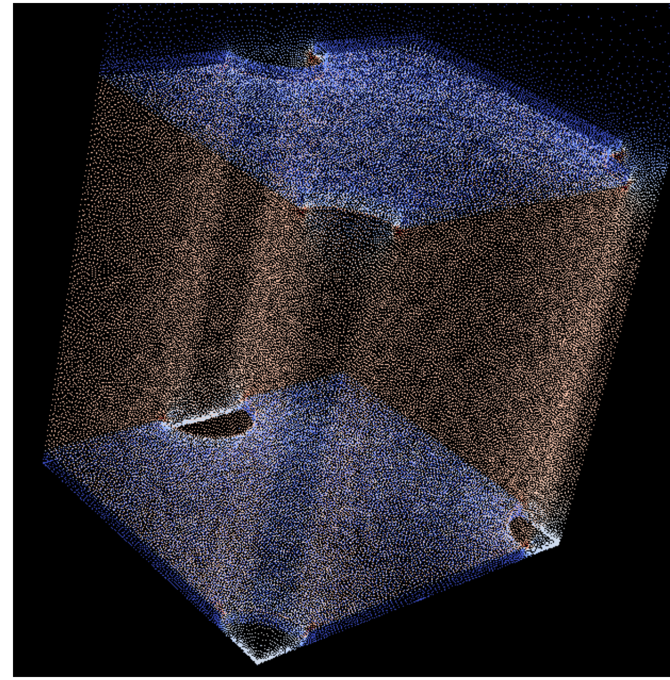
- General-purpose chamber for NEXT EL-tile testing and columnar recombination studies (for application to directional Dark Matter detection).
- Possible use as fission TPC currently under study (see talk of M. Caamaño).

enabling assets V (Finite element simulations + electron transport across scintillation structures)

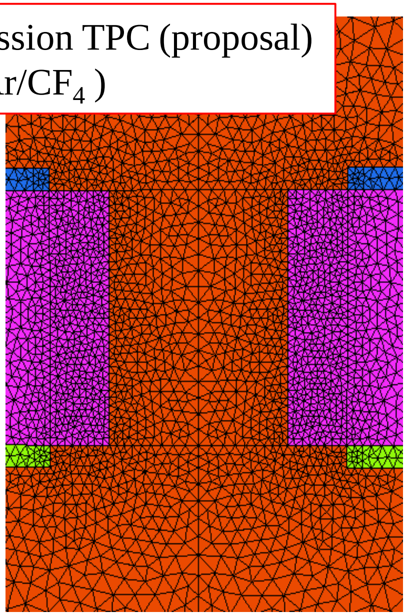
NEXT EL-tile
(xenon-based)

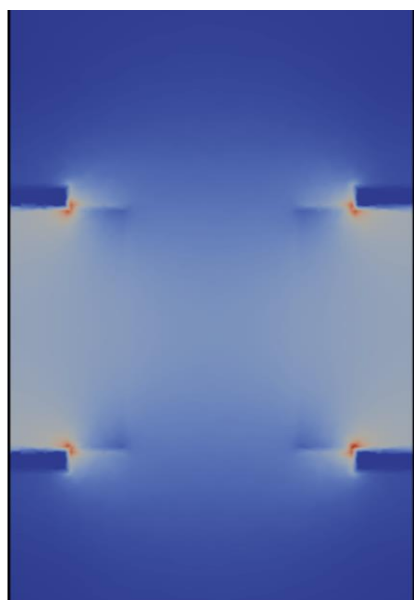


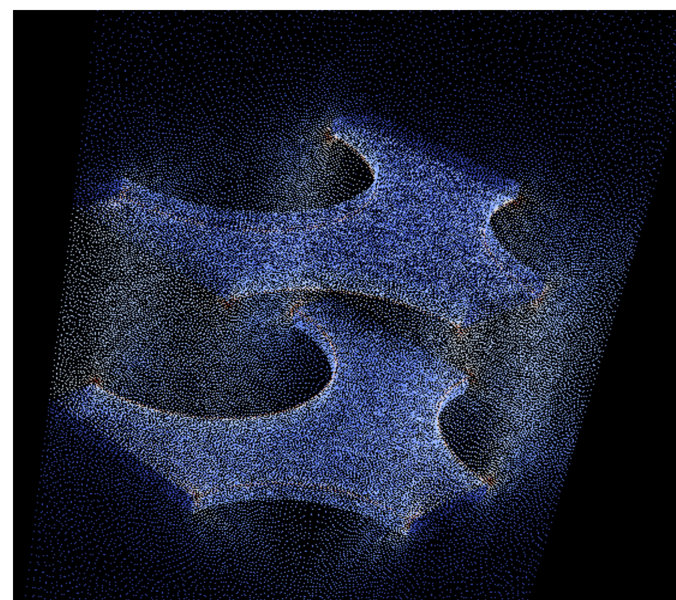




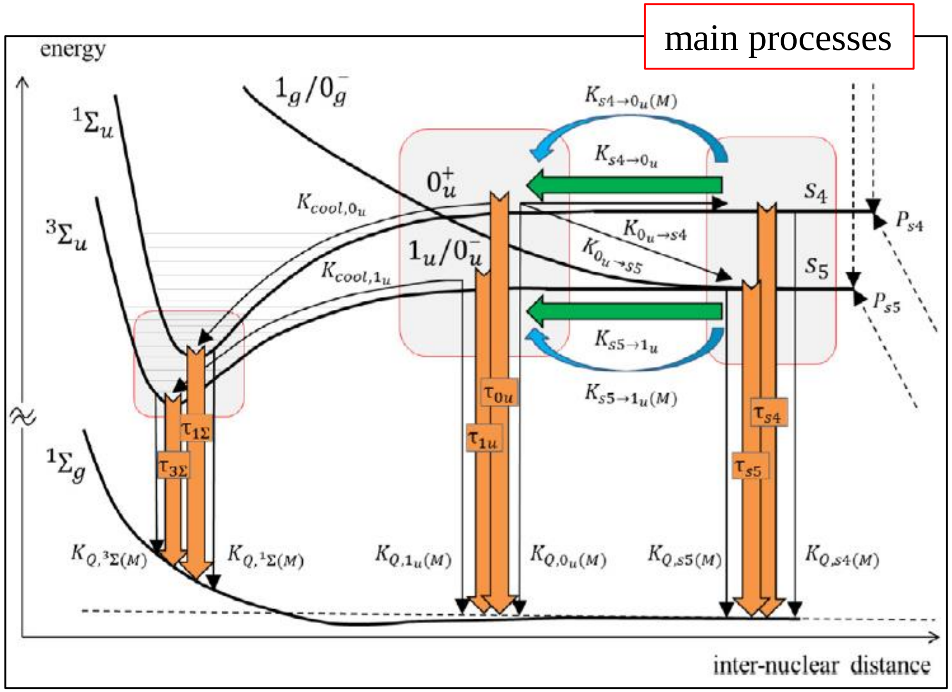
Fission TPC (proposal)
(Ar/CF_4)

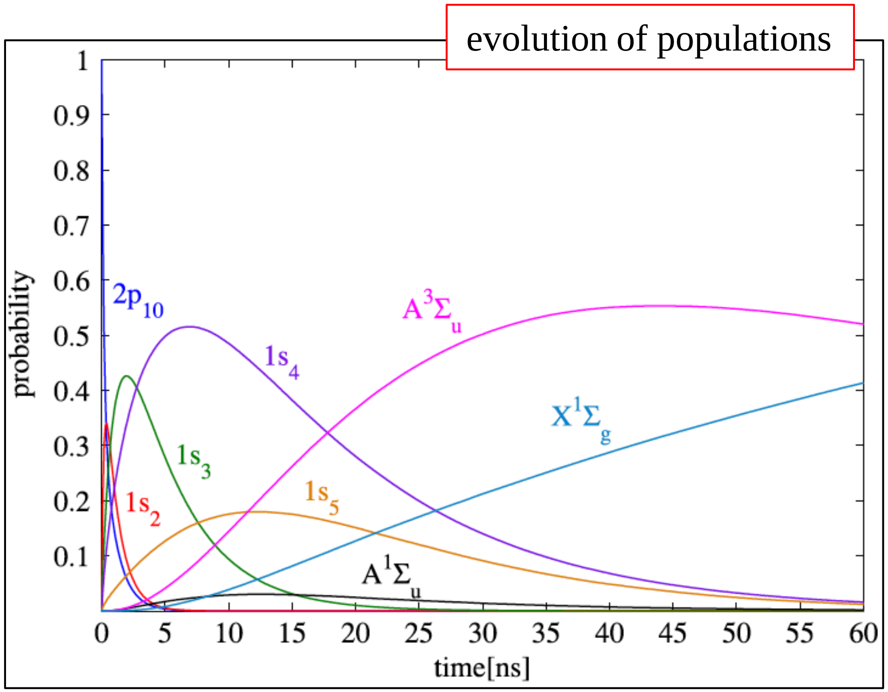


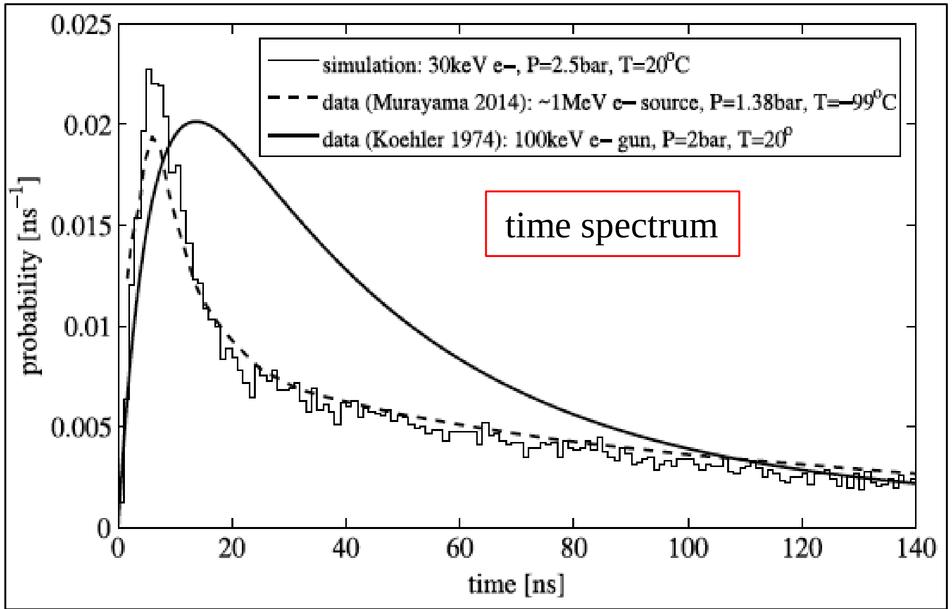


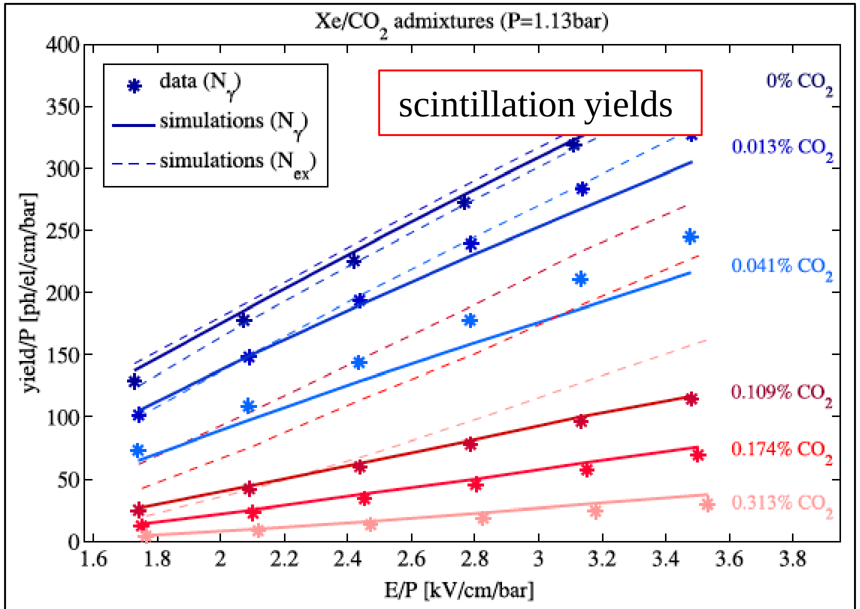


enabling assets VI (full description of cascade of excited states down to scintillation)



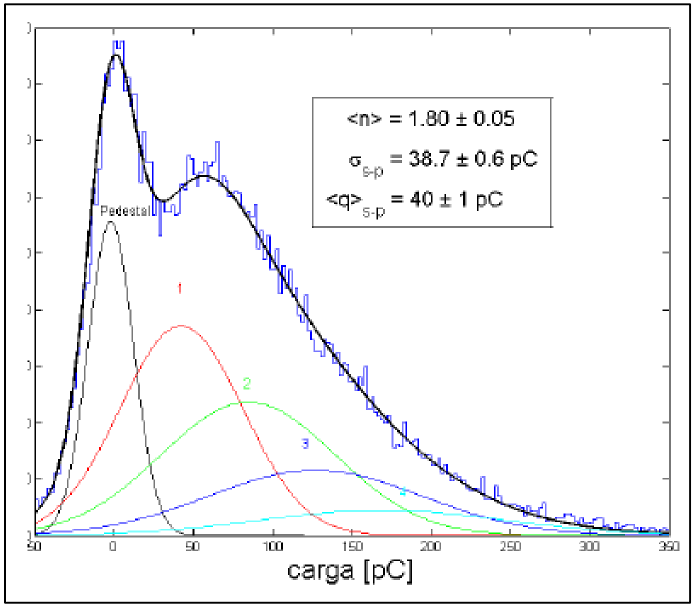




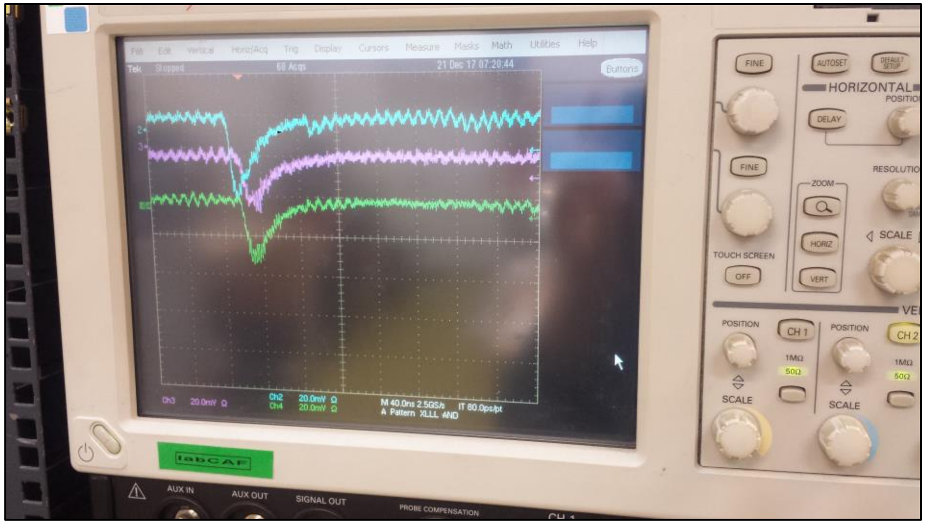


enabling assets VII
(some working parameters achieved)

- Vacuum level achieved (with Nausicaa0 fully assembled): $5x10^{-6}$ mbar (after just one night).
- Gas system pressurized up to 10bar with a leak rate 10^{-5}-10^{-4} mbar l s^{-1}.
- Nausicaa0 rated up to 10bar (presently working at 3bar).
- Single-photon sensitivity proven.
- First results from scintillation from the new NEXT EL-tiles.



(yesterday evening)

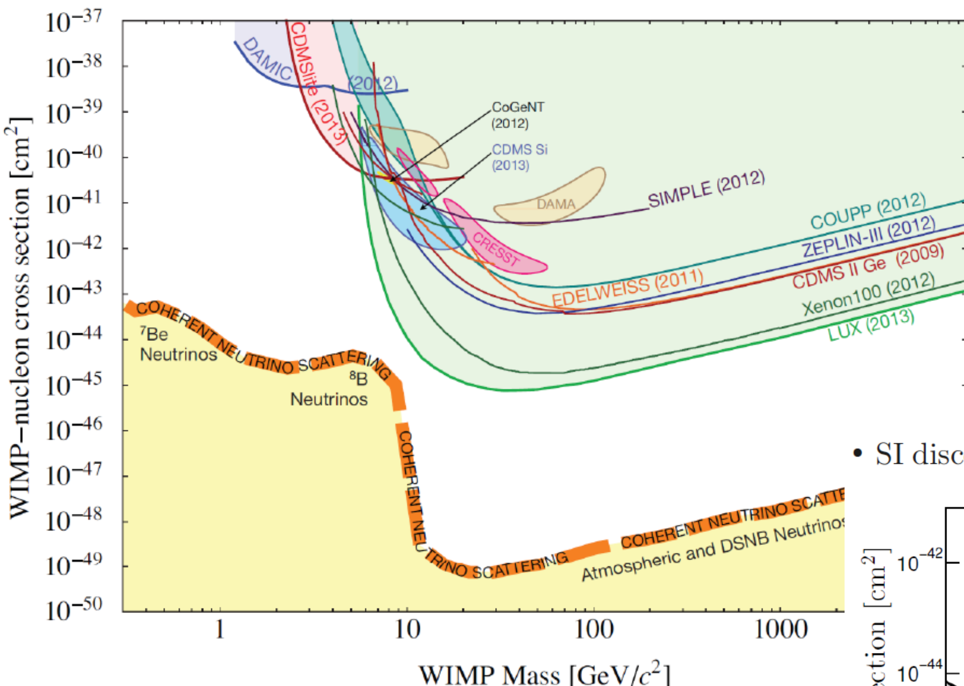


- voltage across the tile: 5kV
- drift field: 1kV/cm/bar
- pressure: 3bar
- signal seen in 3PMTs simultaneously

present collaborators

	framework	Spokesperson/PI	Number of Institutes	official status
NEXT	Spanish Ministry	J.J. Gomez Cadenas (IFIC)/ D. Nygren (Texas Arlington)	~10	existing MOU
Detector development	RD51	L. Ropelewski (CERN) / S. Dalla Torre (INFN)	~90	existing MOU
fission TPC	Xunta	M. Caamaño (IGFAE)	1	gentlemen's agreement
directional dark matter	RD51 common project	E. Baraccini (INFN)	6	No MOU yet (?)
precision x-section measurements / DUNE	Proposal submitted to CERN-SPSC	J. Monroe (Royal Holloway)	~20	No MOU yet (?)
Forest fire detection and monitoring	SUDOE proposal under preparation	J. Veloso (Aveiro)	5-10	-

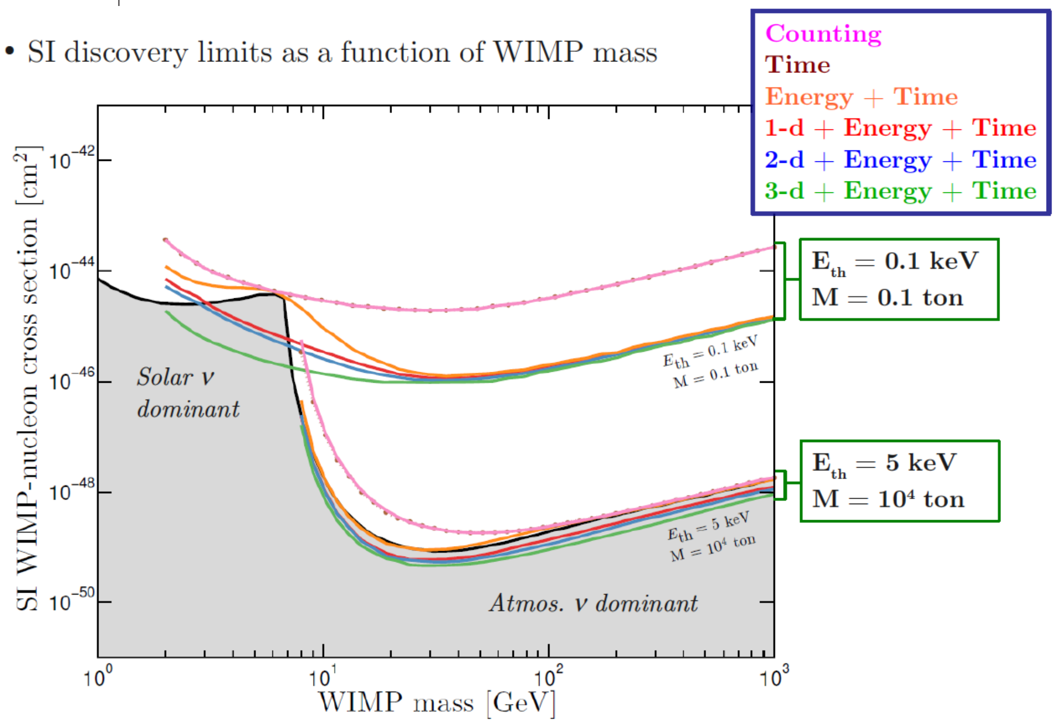
Directional Dark Matter detection (should IGFAE get strongly involved in this activity?)



Two main promising techniques:

- Ultra-low diffusion TPC at low pressure (~50mbar). Negative-ion based.
- High pressure TPC, based on a poorly understood phenomenon: 'columnar recombination'. This would be a revolution, but the process has never been studied for low energy nuclei.

- SI discovery limits as a function of WIMP mass



Precision measurements for neutrino physics (or this other one?)

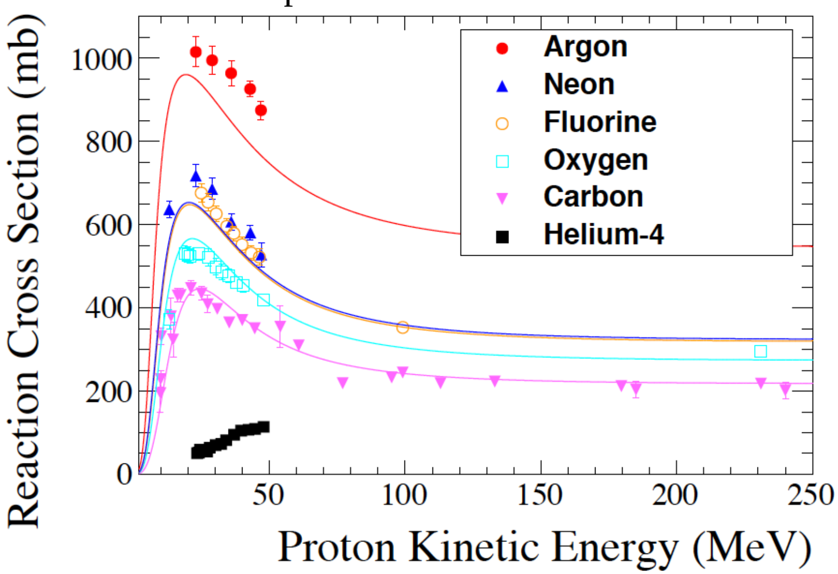
optical TPC proposed by
R-H. for the experiment

Proposal for Measurements of Hadron Scattering with a Gaseous Argon High Pressure TPC for Neutrino Oscillation Measurements

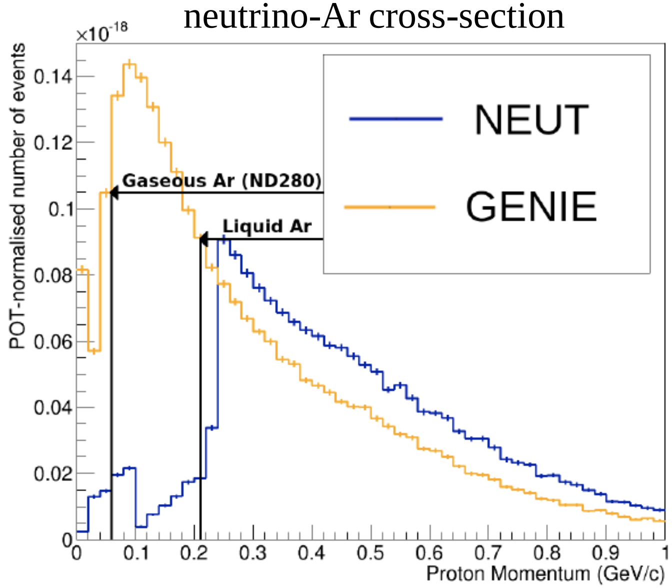
C. Andreopoulos[16], G. Barker[18], S. Boyd[18], D. Brailsford[11], G. Catanesi[5], Z. Chen-Wishart[13], P. Denner[18], P. Dunne[12], C. Giganti[23], D. Gonzalez Diaz[25], J. Haigh[18], P. Hamacher-Baumann[22], Y. Hayato[3], I. Irastorza[24], B. Jamieson[1], A. Kaboth[13], Yu. Kudenko[7], M. Leyton[8], K.-B. Luk[21], W. Ma[12], K.B.M. Mahn[20], J. Martin-Albo[17], M. Martini[2], J. Monroe (P.I.)[13], U. Mosel[26], R.Nichol[15], J.Nieves[9], T. Nonnenmacher[12], J. Nowak[11], W. Parker[13], J.L. Raaf[19], J. Rademacker[14], T. Radermacher[22], E. Radicioni[5], S. Roth[22], F. Sanchez[8], D. Sgalaberna[10], Y. Shitov[12], S. Valder[18], J. Walding[13], M. Ward[13], M.O. Wascko[12], A. Weber[17], M. Yokoyama[4], and A. Zalewska[6]

3% accuracy on systematic errors needed for next generation (DUNE and T2K) experiments!

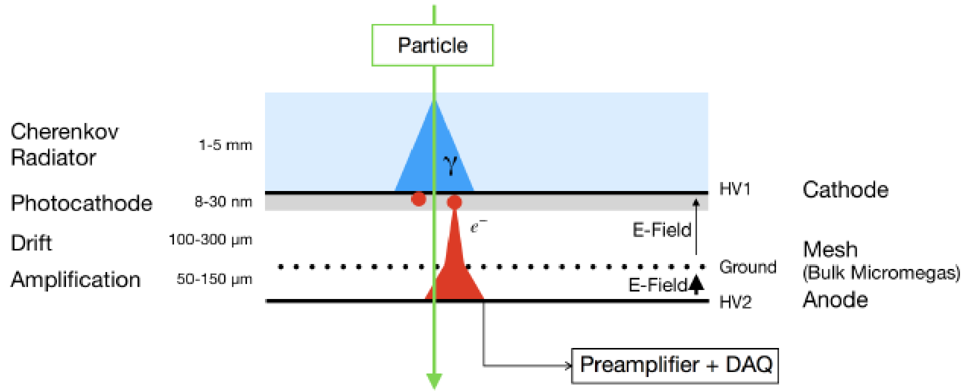
proton-Ar cross-section

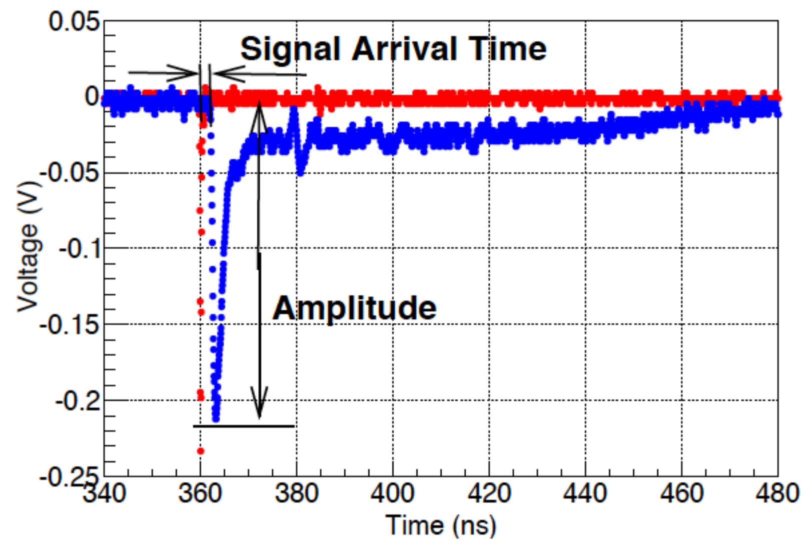


neutrino-Ar cross-section

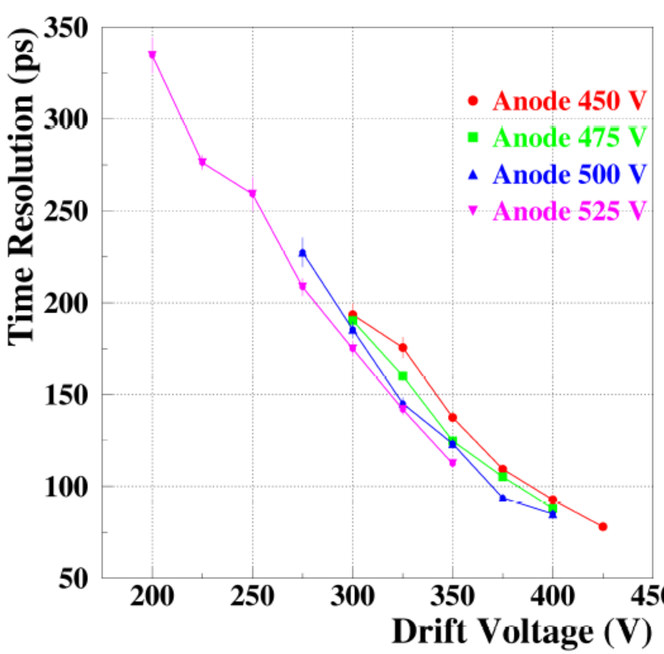


extra: (20ps-level time resolution with gaseous detectors)





single-photon time resolution



time resolution to minimum ionizing particles