update from Bari, courtesy of Gabriella Catanesi

Bari Lab update: April 2024 (from the design to the construction phase)

- Construction of the gas vessel (with flanges and optical window) ongoing (will be installed in the lab July 2024)
- Construction of the table and supports for the vessel also ongoing (will be ready in June 2024)
- Electronic Procurement completed
- Development of readout software started
- Field-cage design in preparation => Construction second half 2024)
- Test of the gas system ongoing
- Goal : prototype ready by end of the year

Identification of a Gas Mixture For Neutrino Physics in an Optical TPC

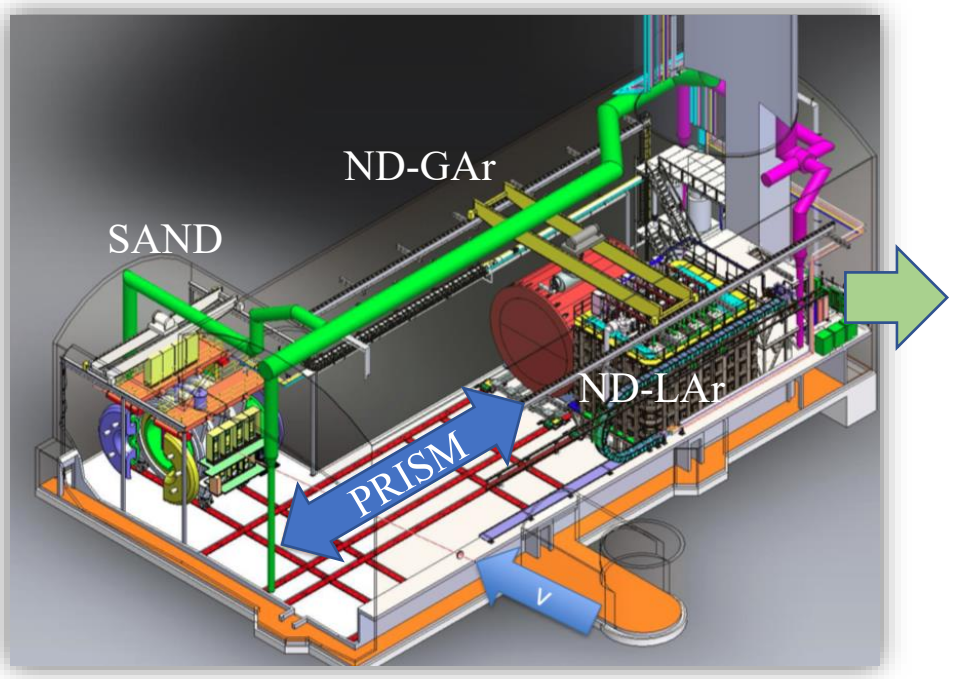
P. Amedo[1], J. Baldonedo[2], C. Benítez[3], E. Casarejos[2], J. Collazo[2], D. J. Fernández[1], R. Hafeji[1,3], D. González-Díaz[1], S. Leardini[1], J. Llerena[1], J. Martín-Albo[3], D. Rodas Rodríguez[1], A. Saá-Hernández[1], A. Segade[2], M. Tuzi[3]
and the ARIADNE team[4]

1. IGFAE (Santiago); 2. Univ. Vigo; 3. IFIC (Valencia); 4. Univ. Liverpool

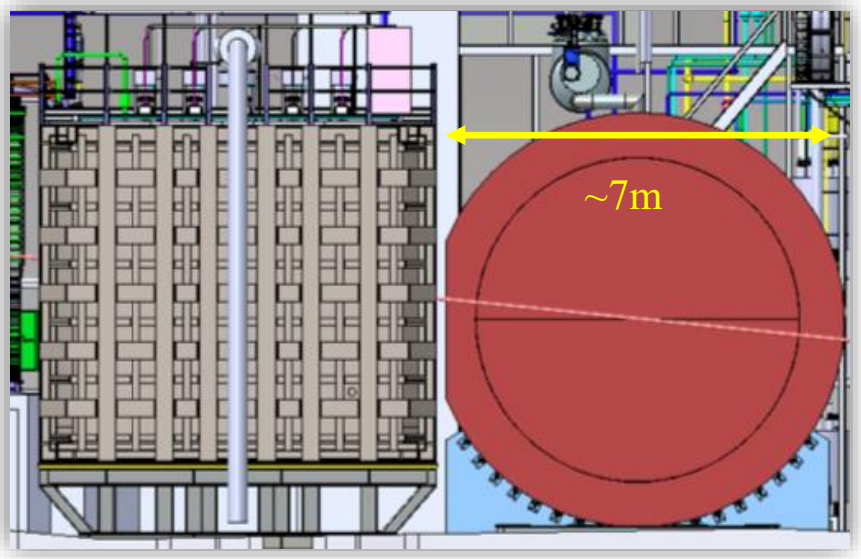
*ULTIMATE: Unleashing Light Timing In a Massive Argon TPC Experiment (Spanish Ministry -FPN)

Main context: DUNE's ND-GAr (planned for Phase-II)

DUNE Phase-II

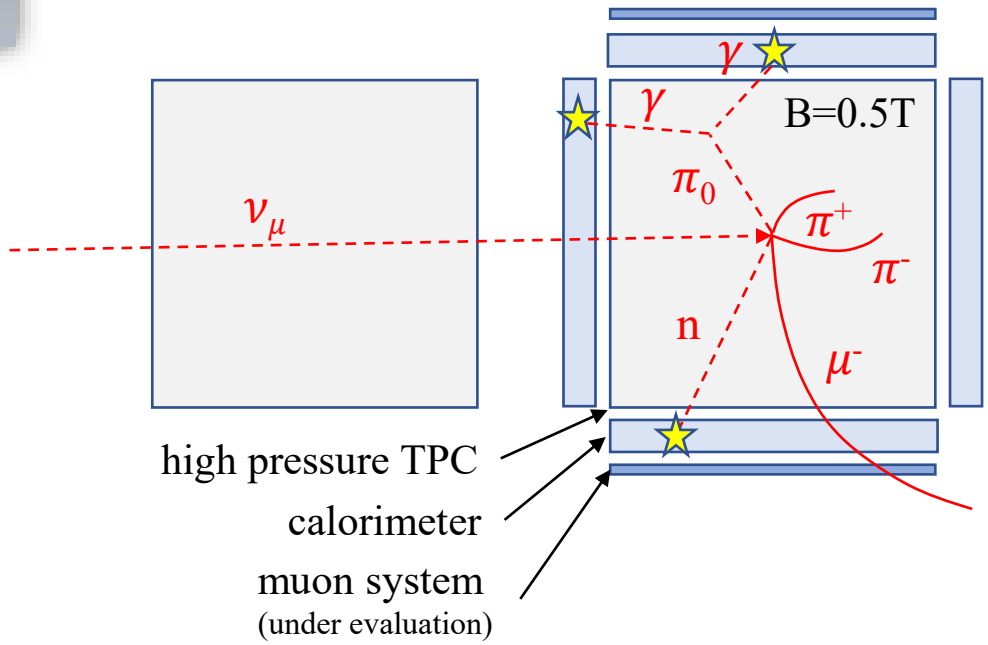


ND-LAr ND-GAr



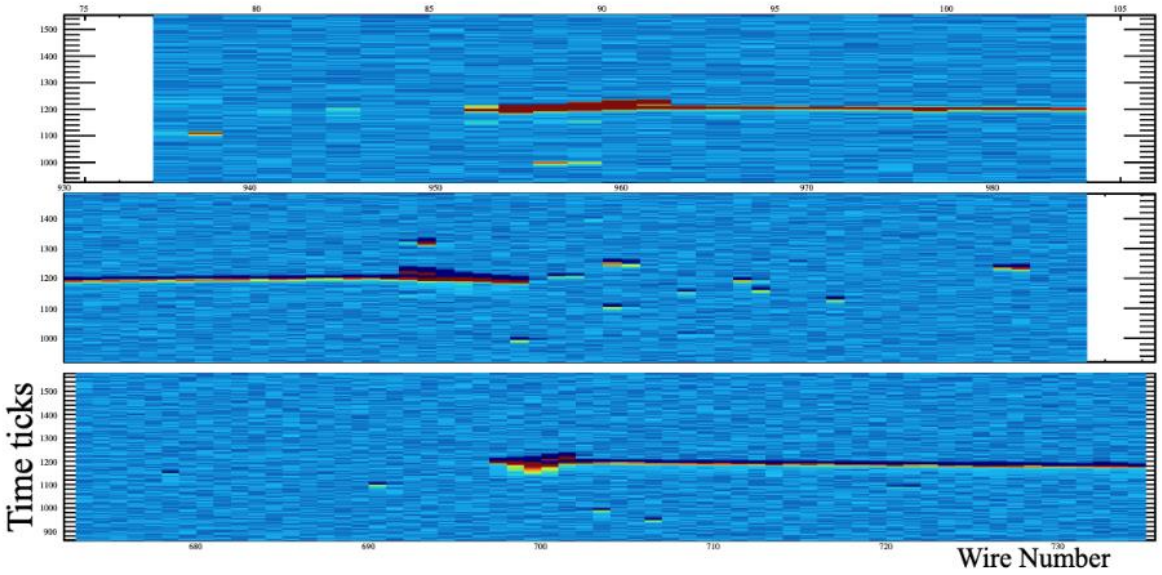
ν_μ-CC:
1.64 x 10^6 evt/ton/yr
ν_μ-NC
5.52 x 10^5 evt/ton/yr

*possible thanks to pressurization, detector size and ν-beam power!

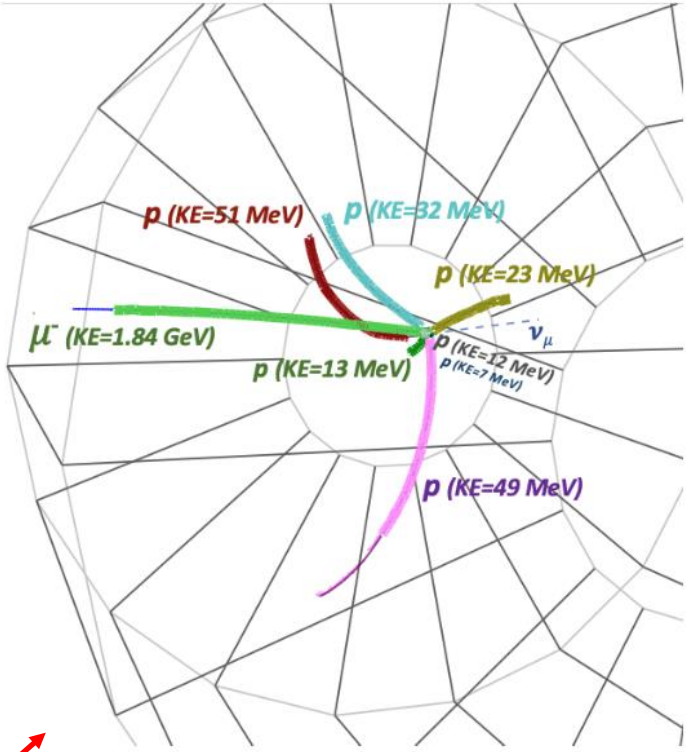


LAr vs GAr

LAr TPC

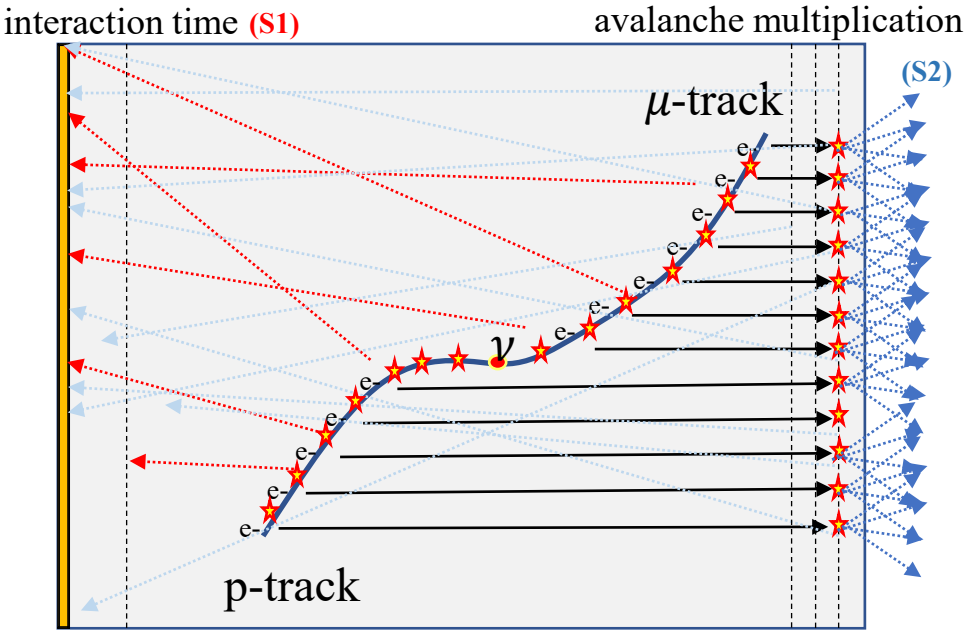


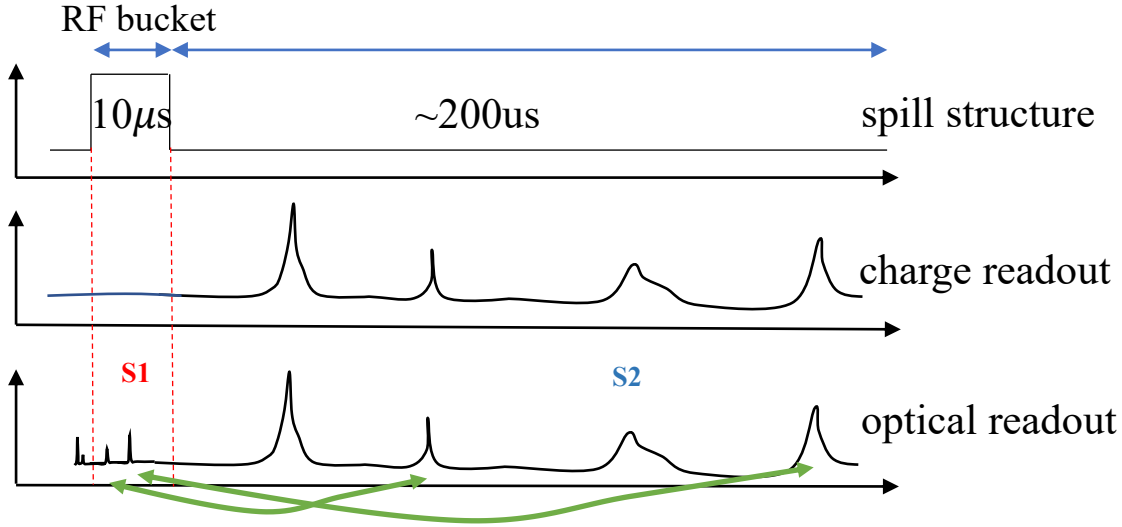
GAr TPC



same event

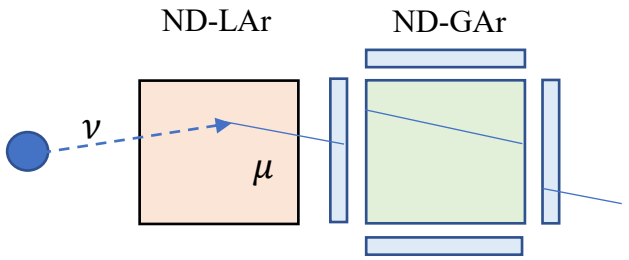
ND-GAr with OTPC readout (original motivation -> provide T_0!)



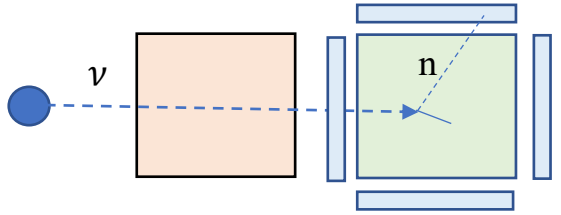


plainly speaking: the feature is <u>useful</u> for track-matching and <u>essential</u> when no charged particle reaches ECAL

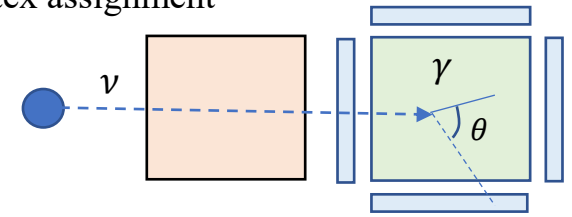
a) Improved track matching with ND-LAr



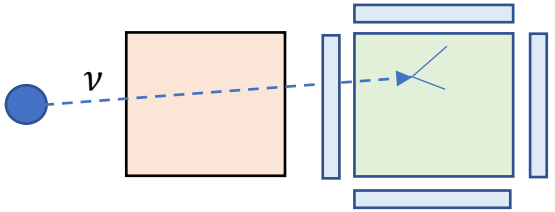
b) Neutron reconstruction via ToF



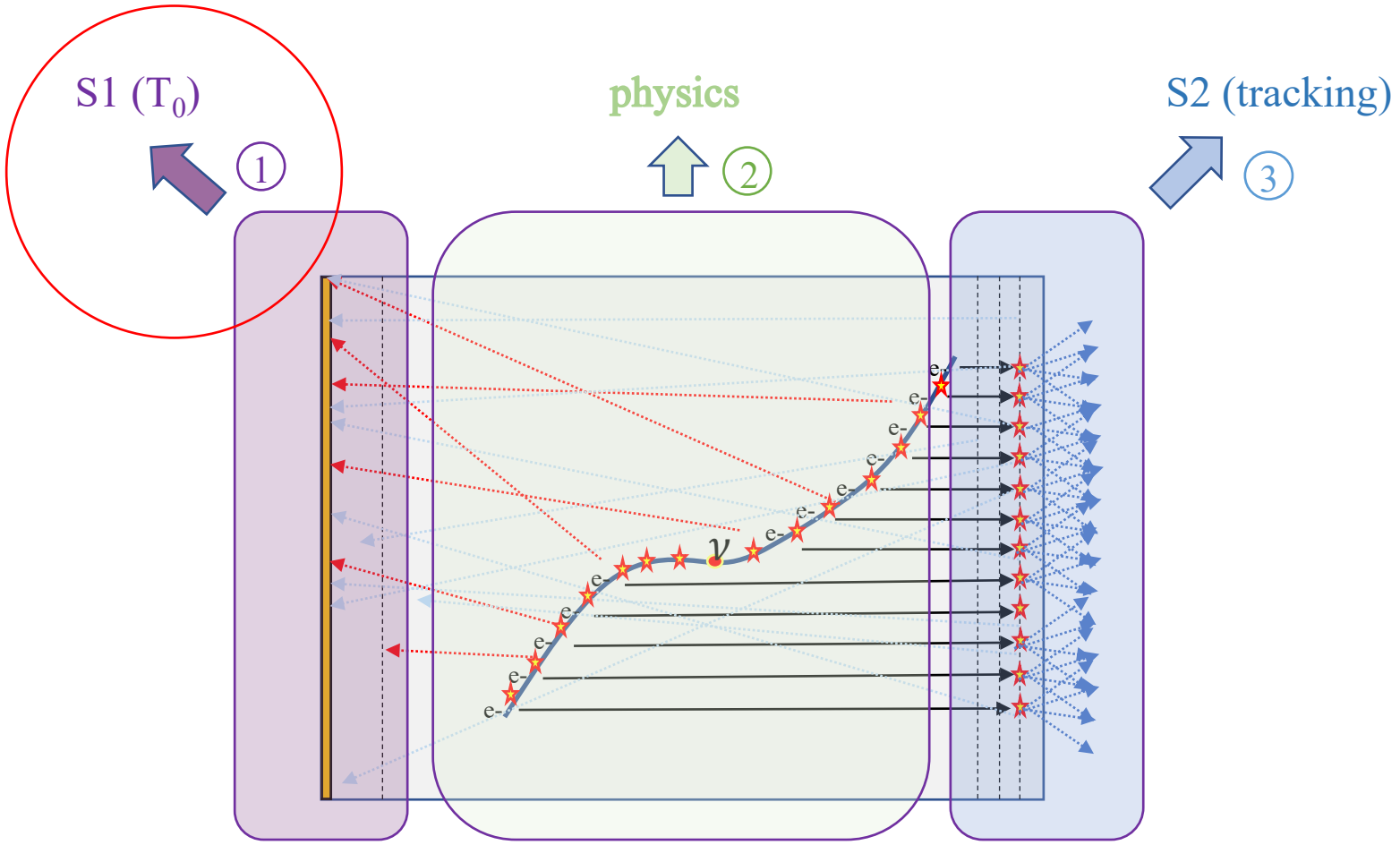
b') Improved n, γ angular reconstruction, vertex assignment



c) Low energy physics and BSM



OTPC readout (main topics)

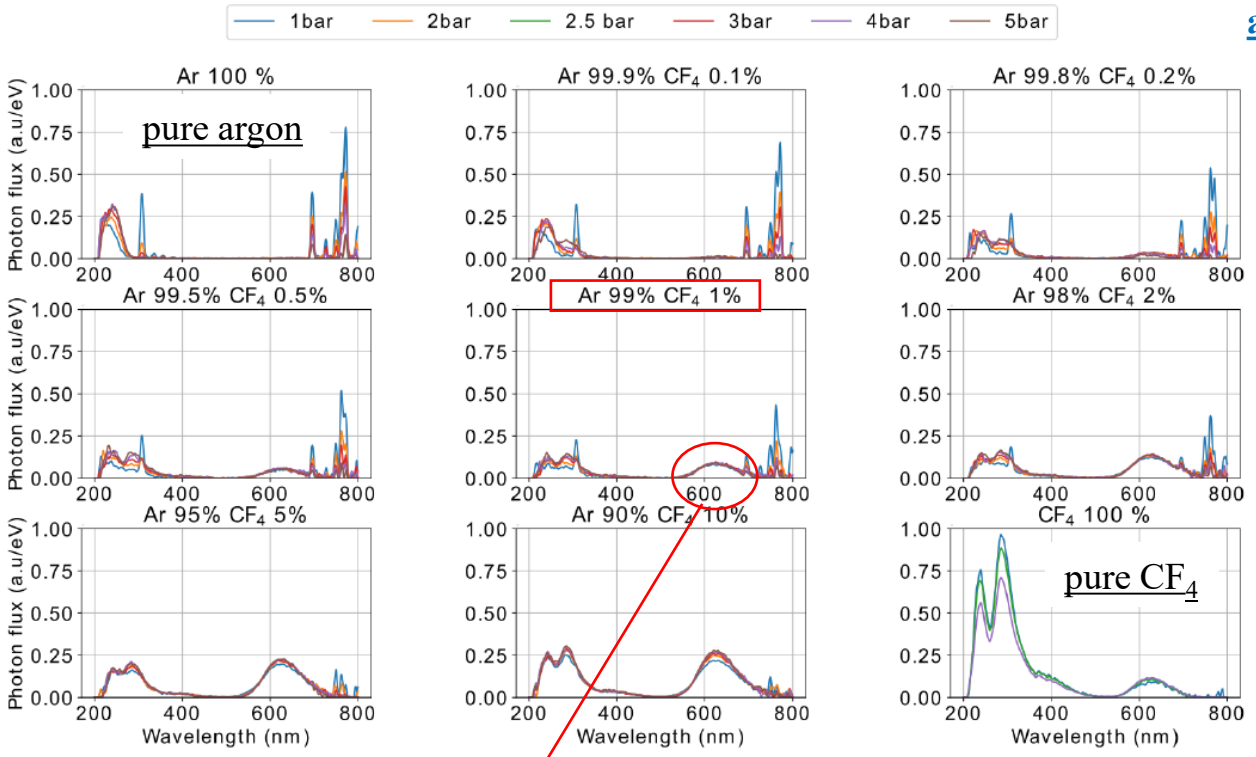


S1(T_0): Primary scintillation in Ar/CF_4

P. Amedo et al., Front. Detect. Sci. Technol. 1:1282854.

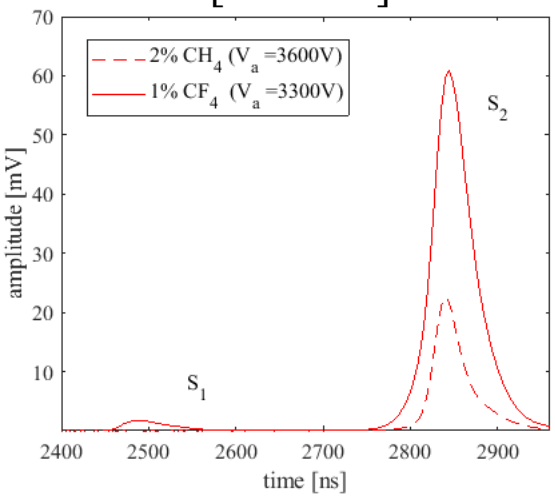
arXiv:2306.09919

spectroscopic

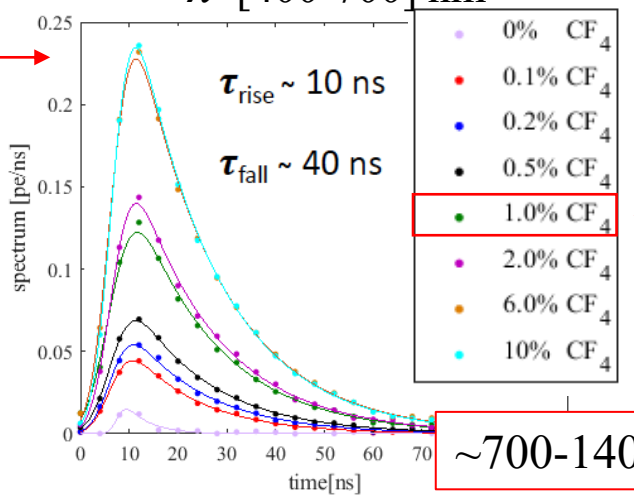


time-resolved

λ=[400-700] nm

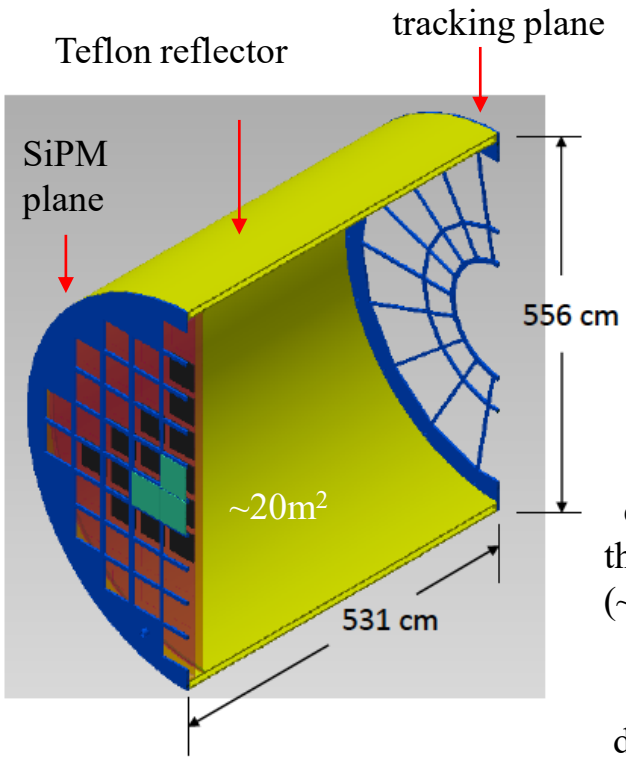


λ=[400-700] nm

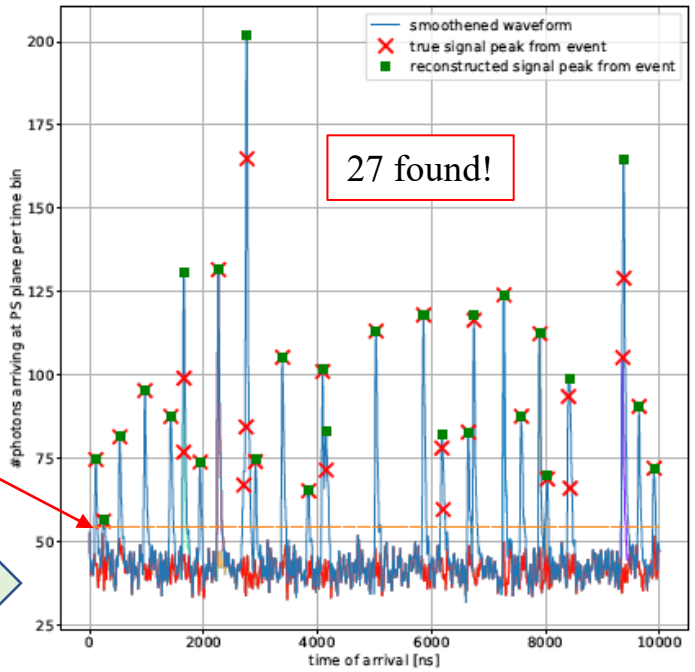


~700-1400 ph/MeV

$S1(T_0)$: Primary scintillation detection (Geant4)



simulated reconstruction for 33 bckg muons (10us spill)

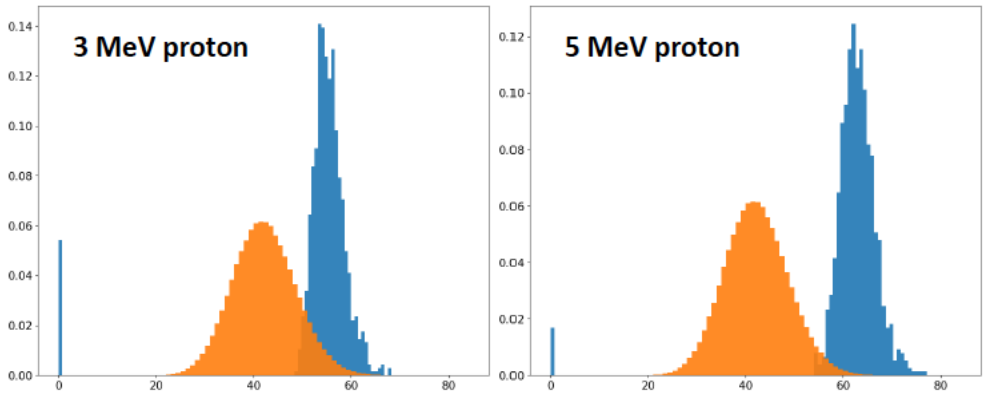


A. Saá et al
arXiv: 2401.09920

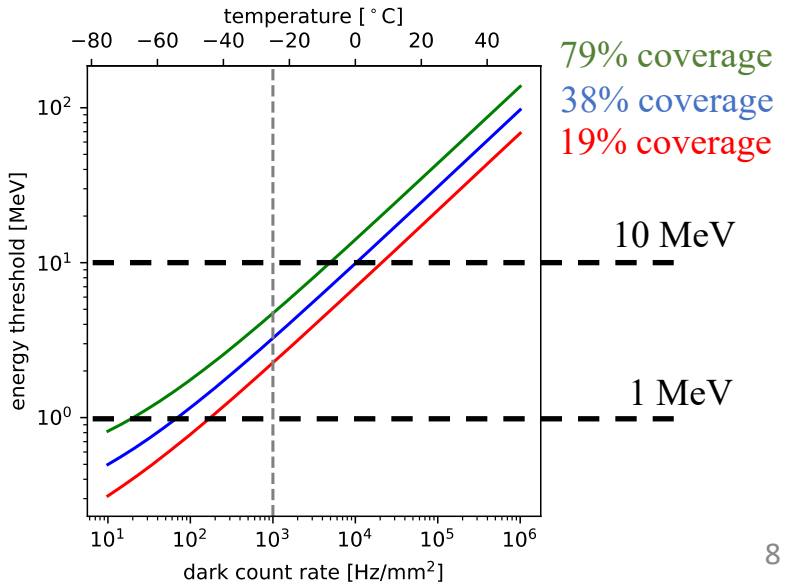
energy threshold (~5MeV)

SiPM dark rate (-25deg)

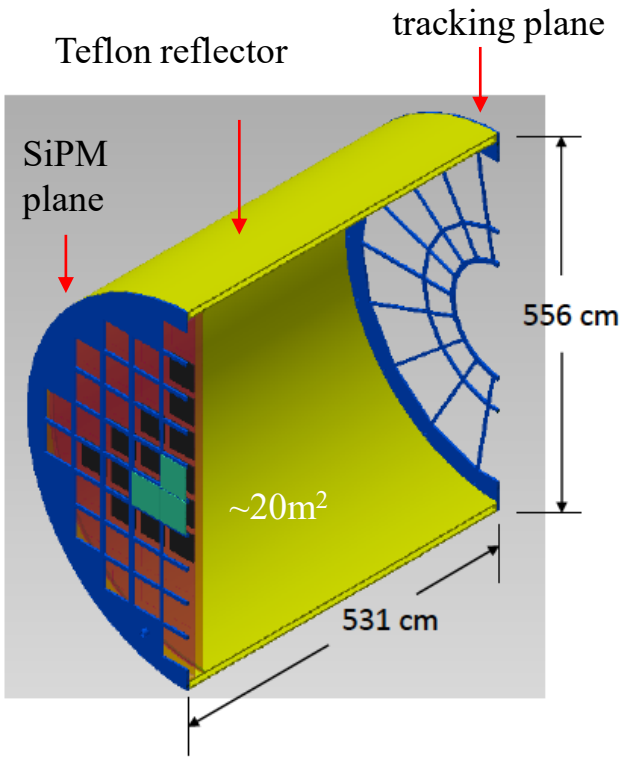
noise/signal separation plots



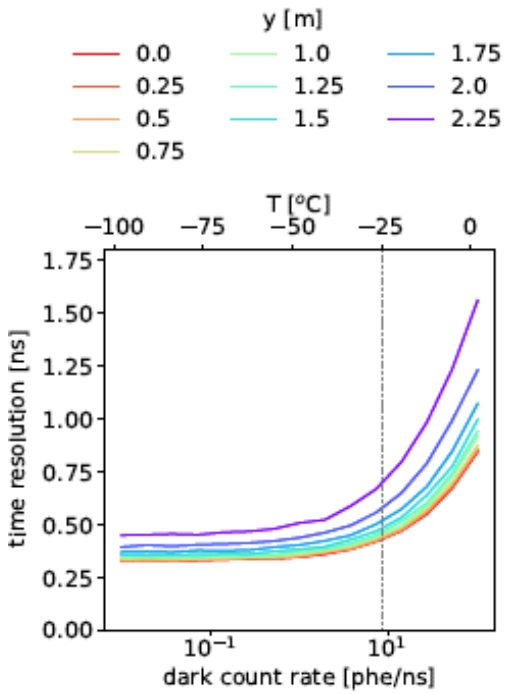
3-sigma separation



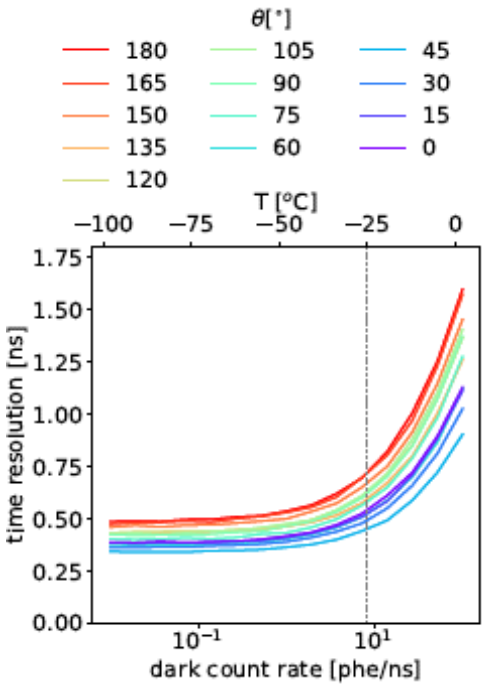
S1(T_0): Primary scintillation detection (Geant4)



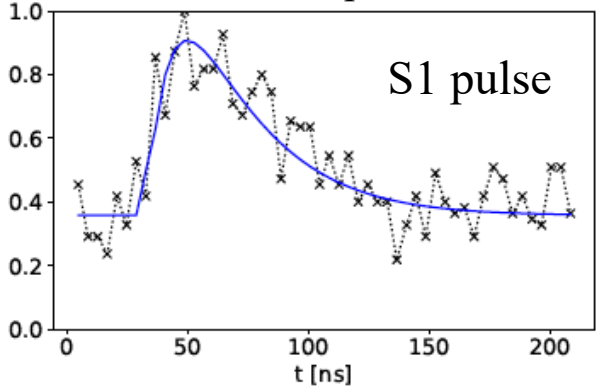
external



internal



reconstruction performance

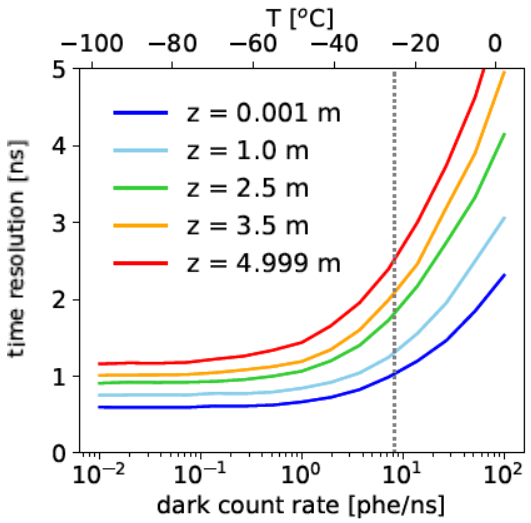


muons

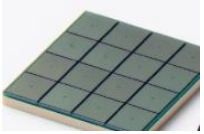
(<10% energy resolution)

5MeV hadrons

(~30% energy resolution)

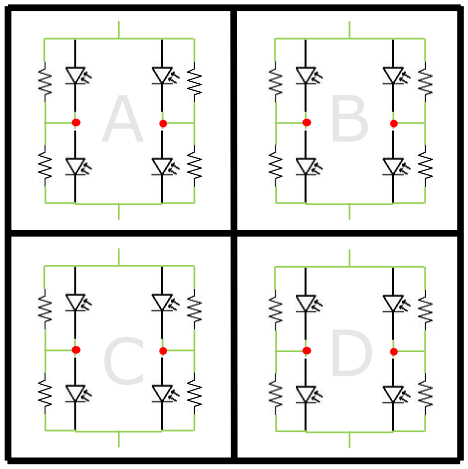


Enabling asset I (SiPM ganging)

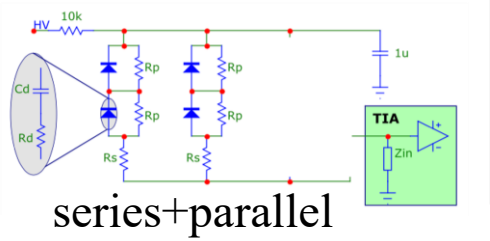


Hamamatsu
S14161-6050HS

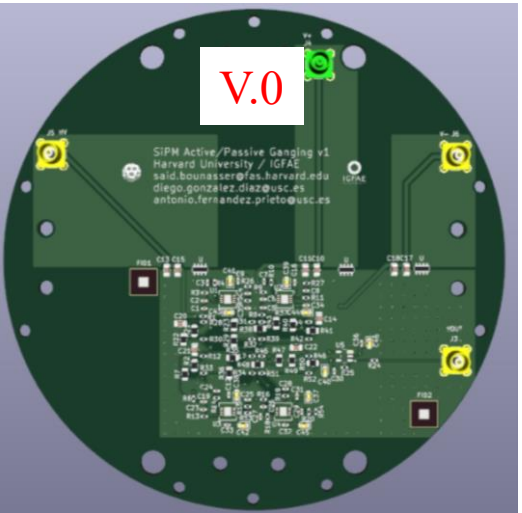
S1(T_0): ganging (board V.0)

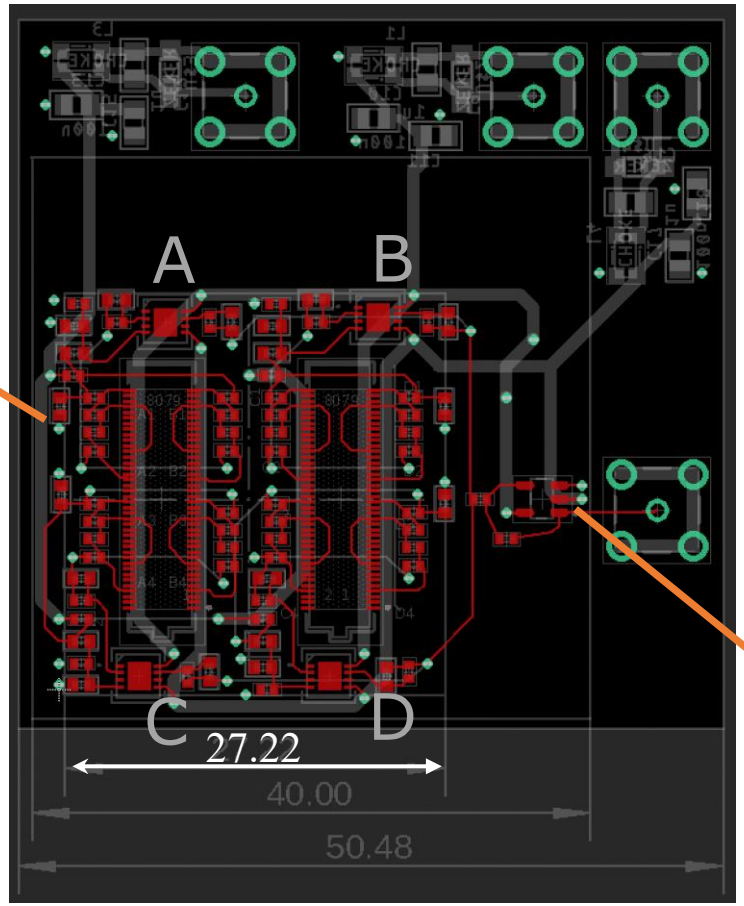


passive ganging

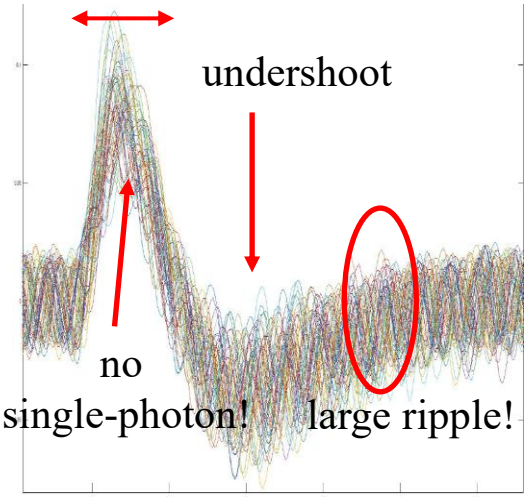


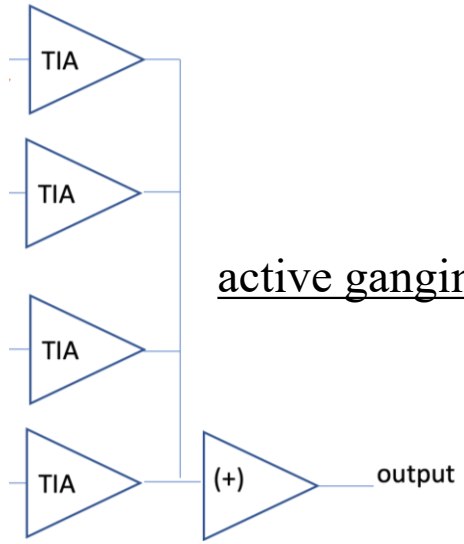
series+parallel





100ns



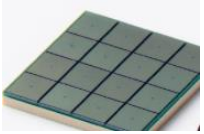


active ganging

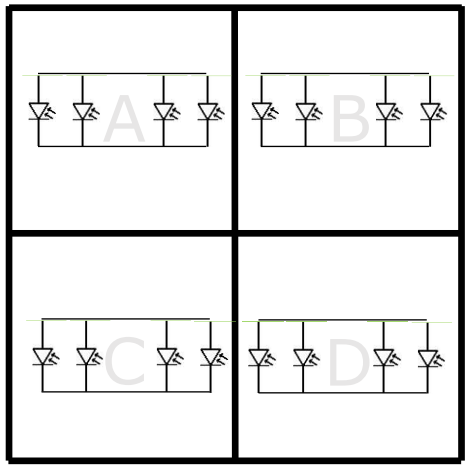
FEE requirements (from simulation)

- Risetime: 10-15ns, width: 50-100ns
- S/N>5
- Power consumption: 100mW
- Fit into 2.5cm x 2.5cm footprint.
- Time sampling ≲7ns.

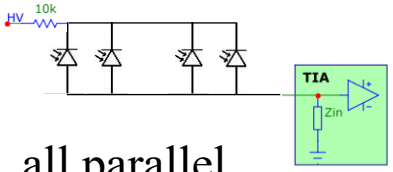
S1(T_0): ganging (board V.1)



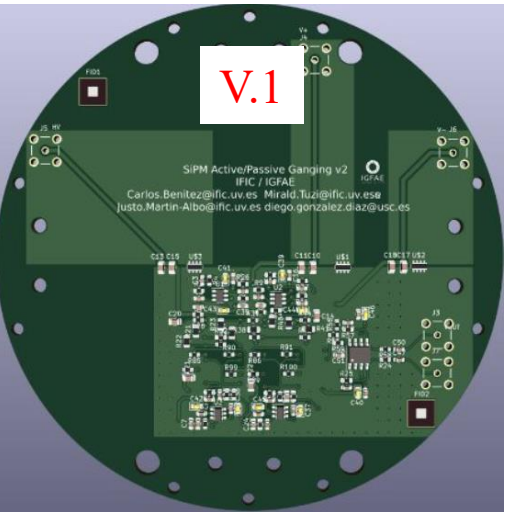
Hamamatsu
S14161-6050HS

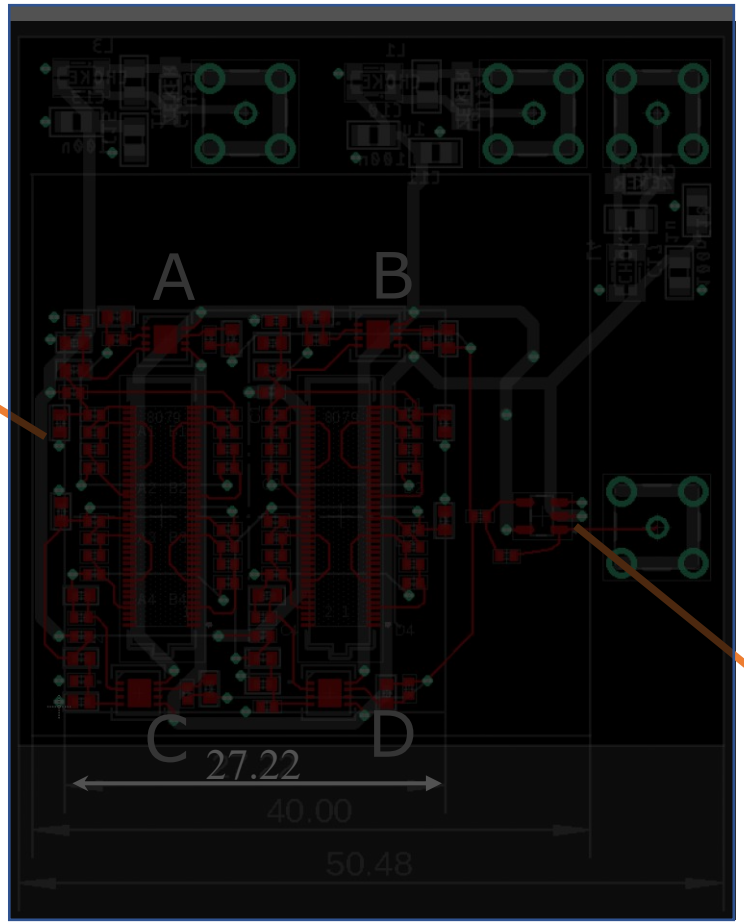


passive ganging



all parallel

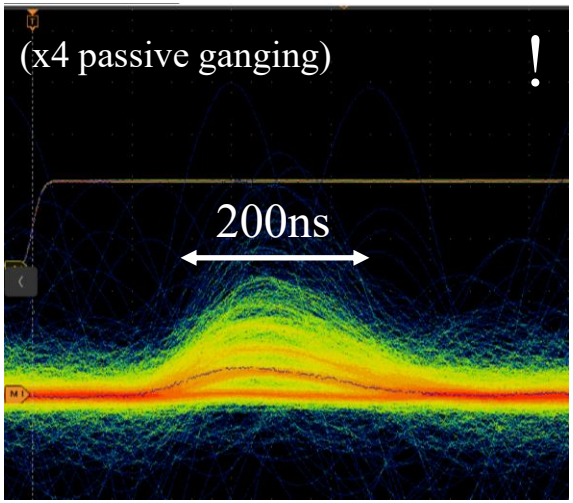


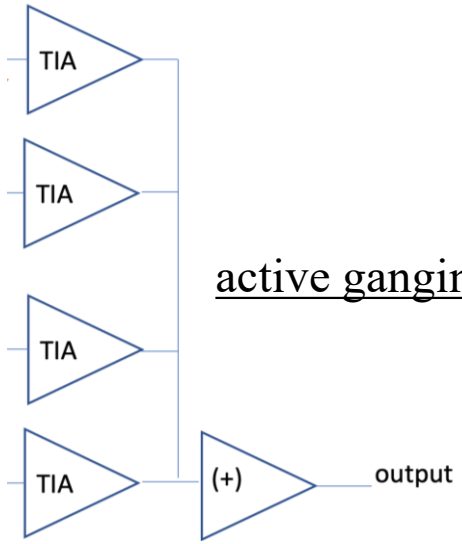


FEE requirements (from simulation)

- Risetime: 10-15ns, width: 50-100ns
- S/N>5
- Power consumption: 100mW
- Fit into 2.5cm x 2.5cm footprint.
- Time sampling ≲7ns.

results at -25deg

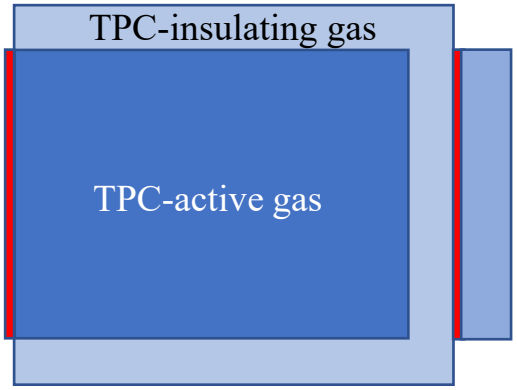




active ganging

V.2 under production!

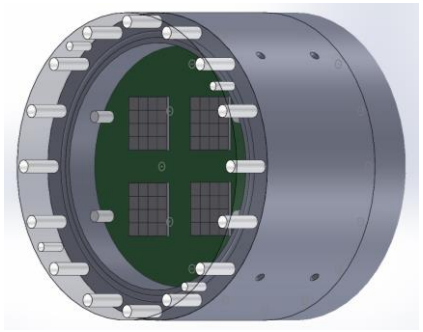
Enabling assets II (active cryostat)

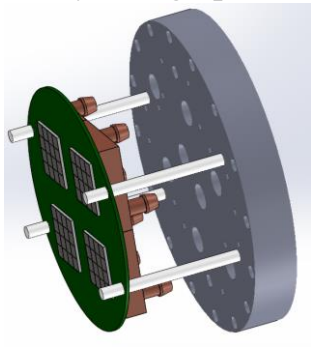


Active cryostat (p.o.c.)

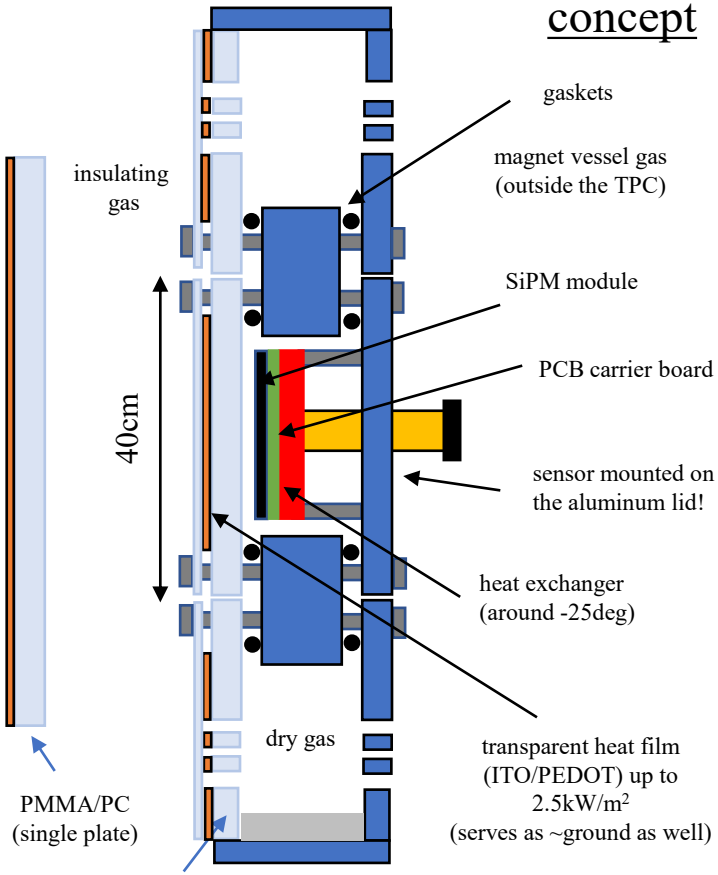
photosensor plane

* A conventional passive cryostat might work, but tricky at high pressure



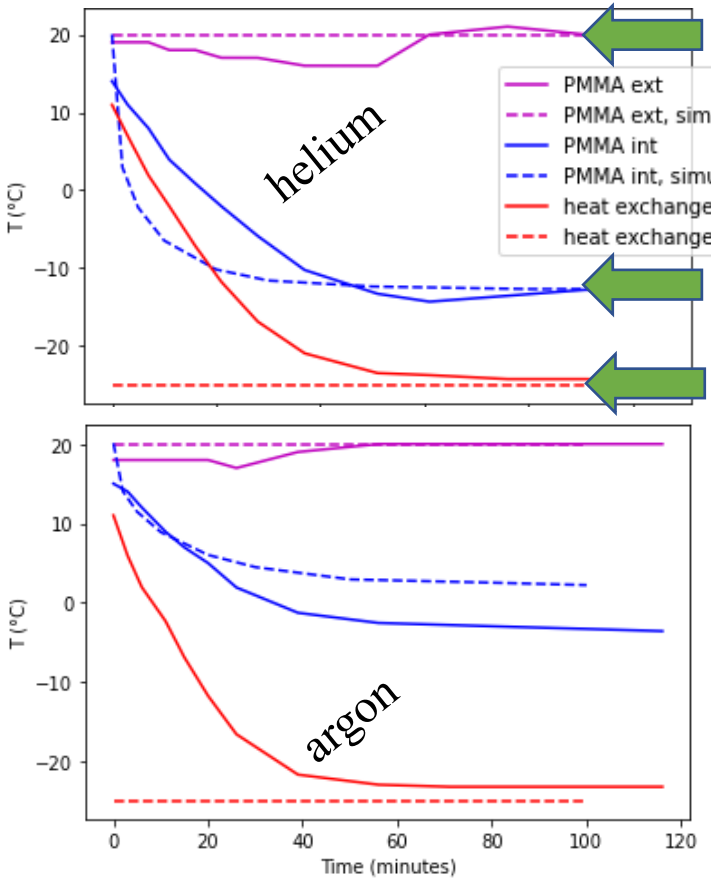


concept



using individual PMMA/PC windows (20mm-thick) to minimize thermal stress (due to TEC) down to manageable levels

*not to scale



window (out)

window (in)

SiPM region

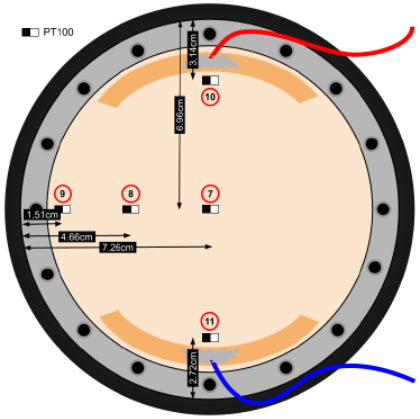
it works!

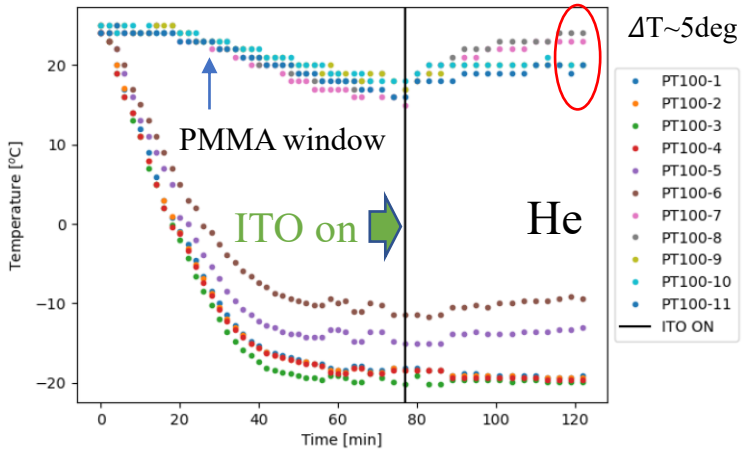
(~100W/m²)

* Measurements at the window center

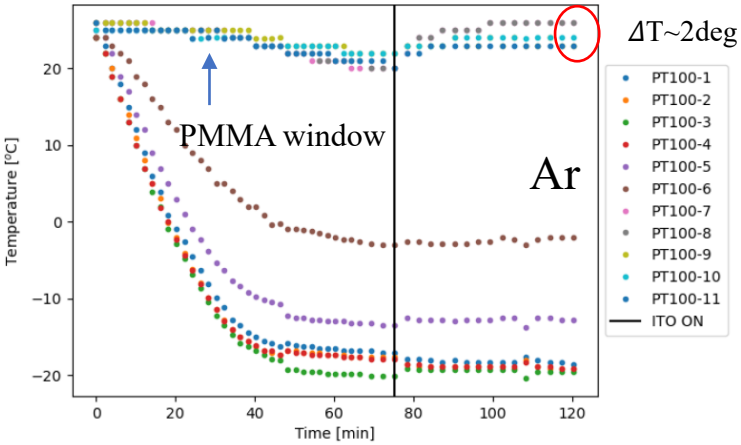
Active cryostat (3D)

PT100's





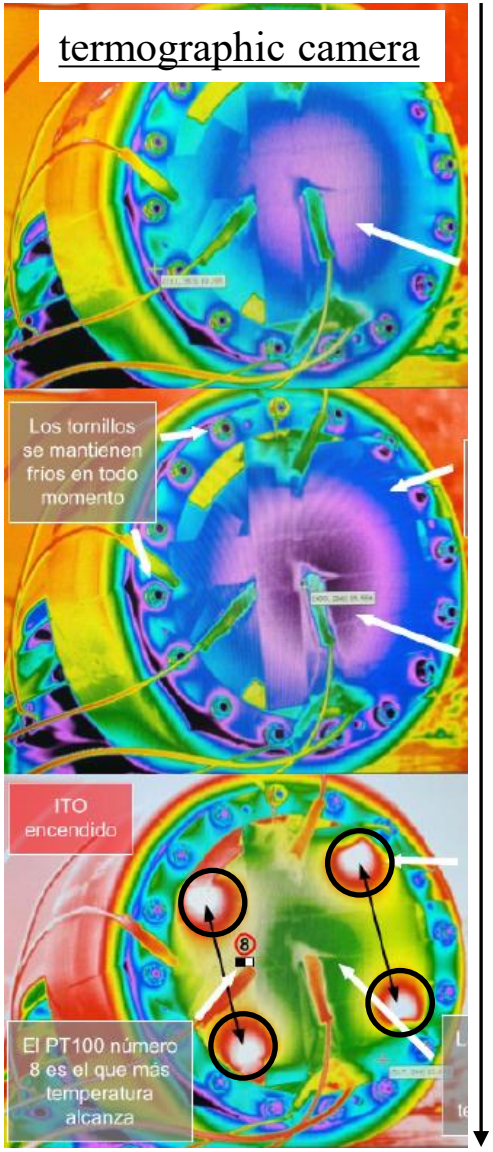
ΔT~5deg



ΔT~2deg

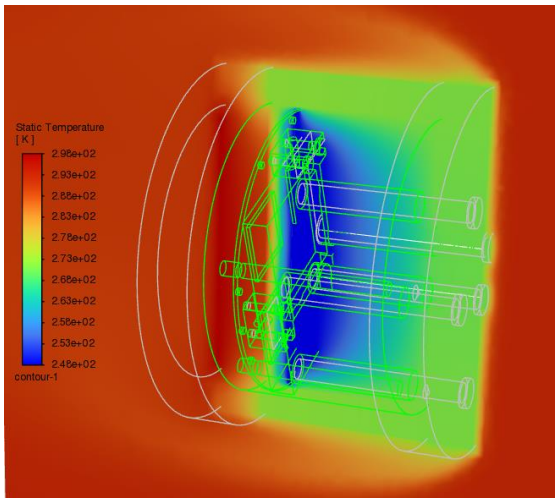
termographic camera

time



problem of heat-dissipation at ITO-electrode edges!
(solved in new design)

3D simulation



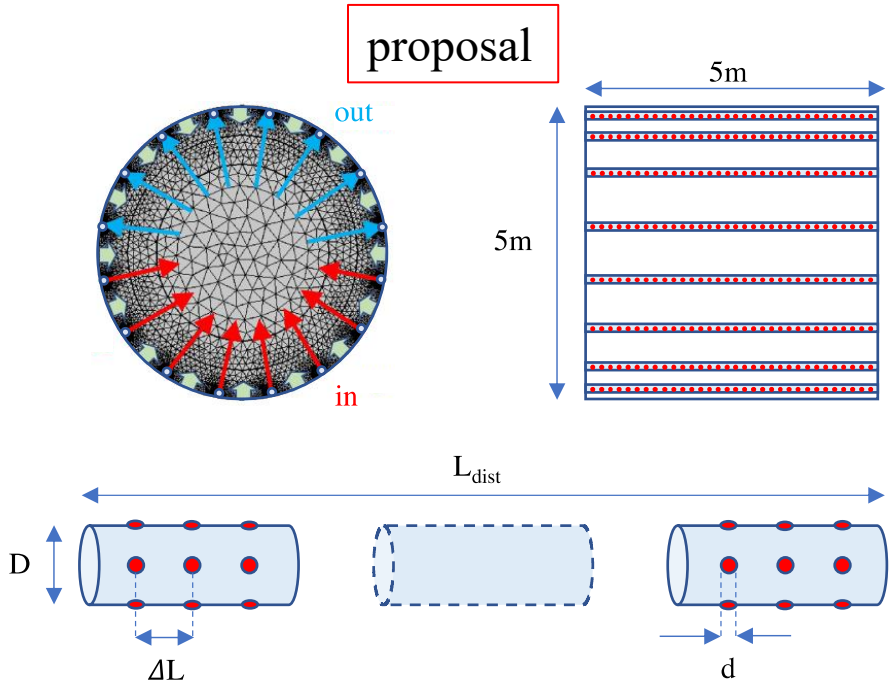
working towards TPC-integrated design

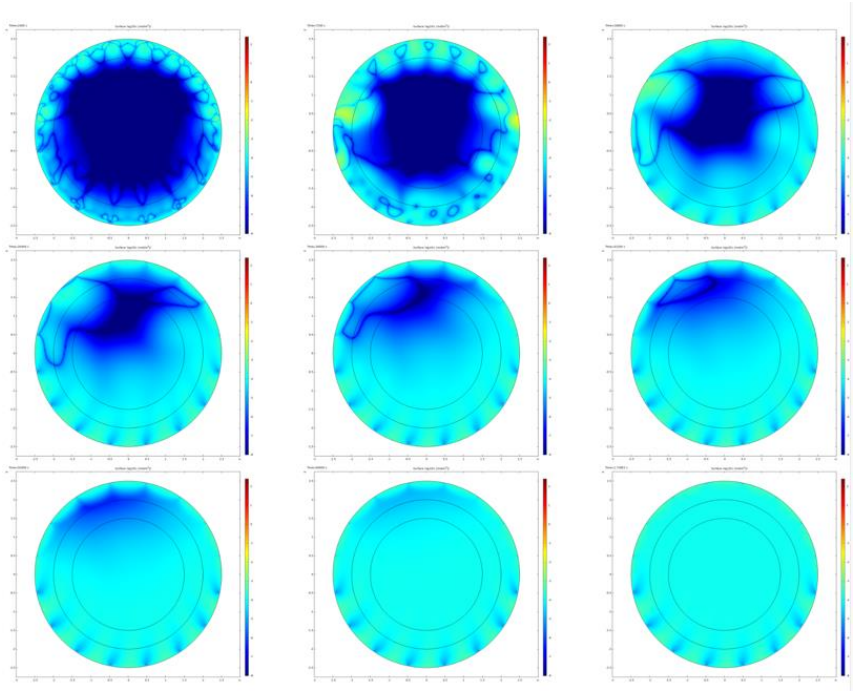
goal: avoid T-gradients in the TPC!

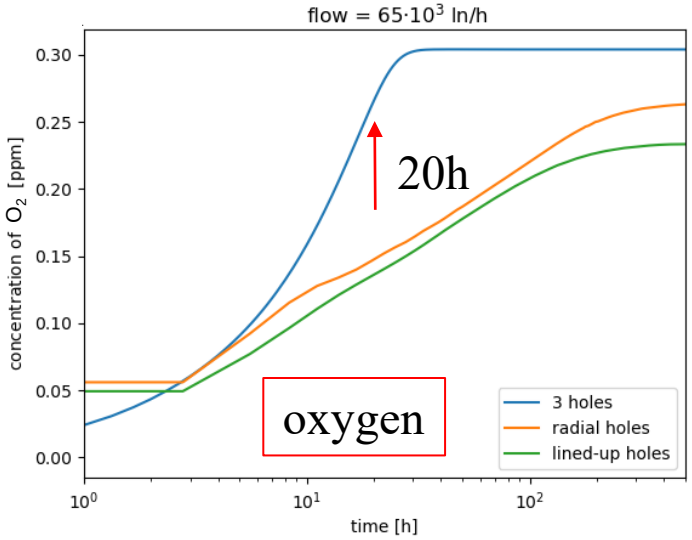
Enabling assets III (impact of Teflon reflector)

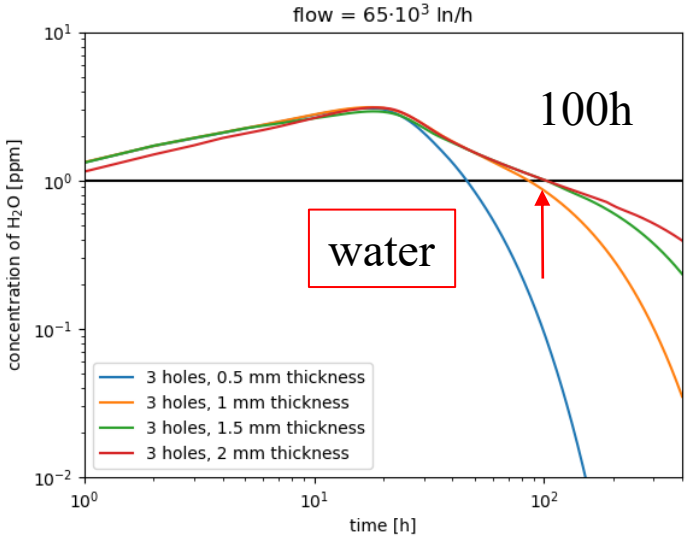
Impact of Teflon reflector

a Teflon reflector involves a lot of plastic facing the active region (can it be efficiently removed?)



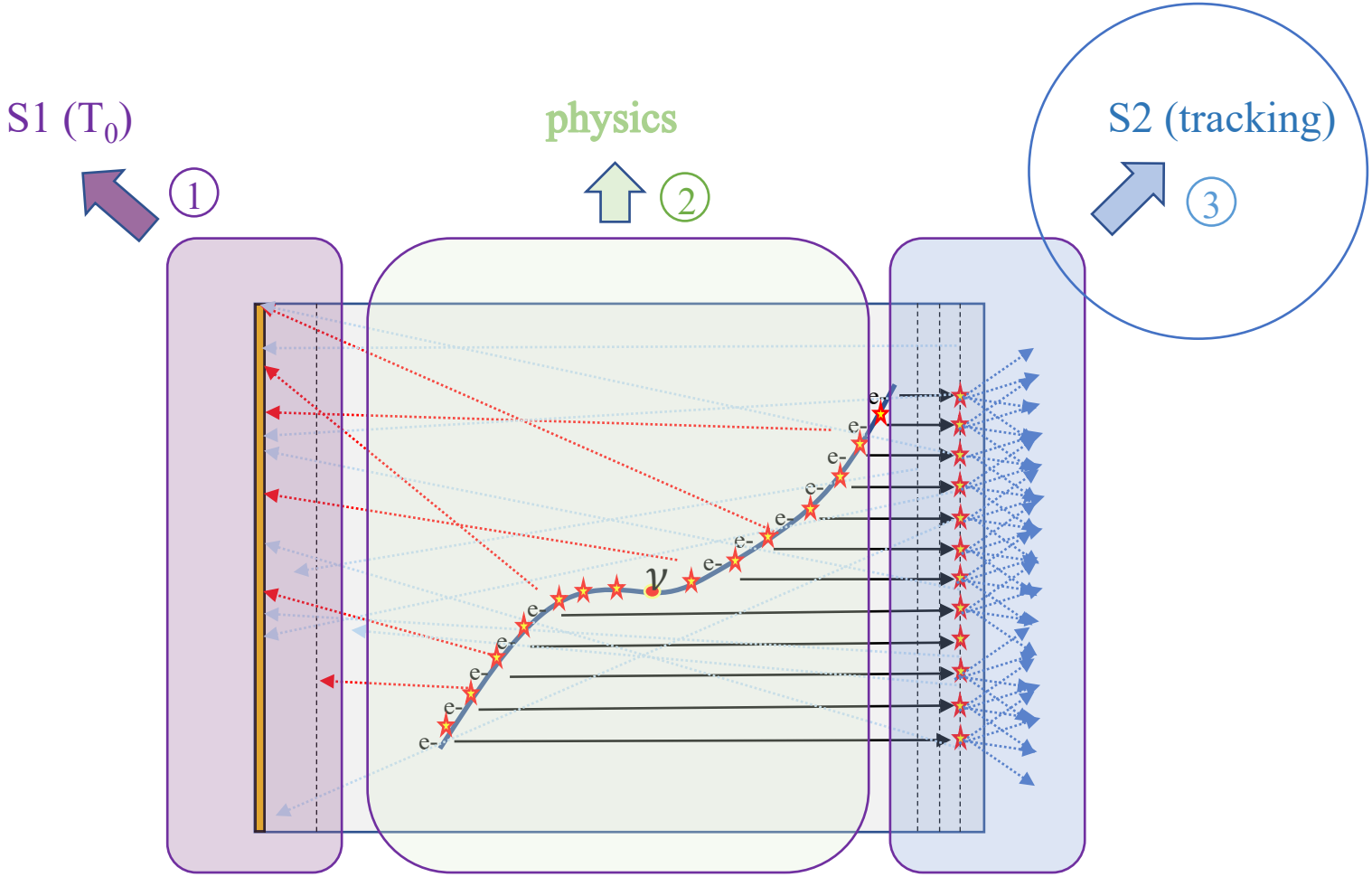






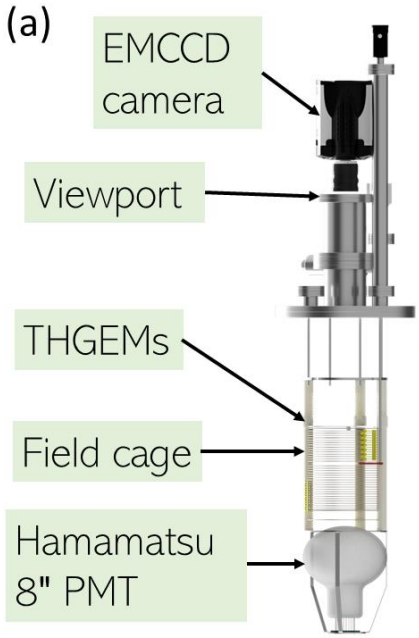
‘Bonus’ asset (optical tracking)

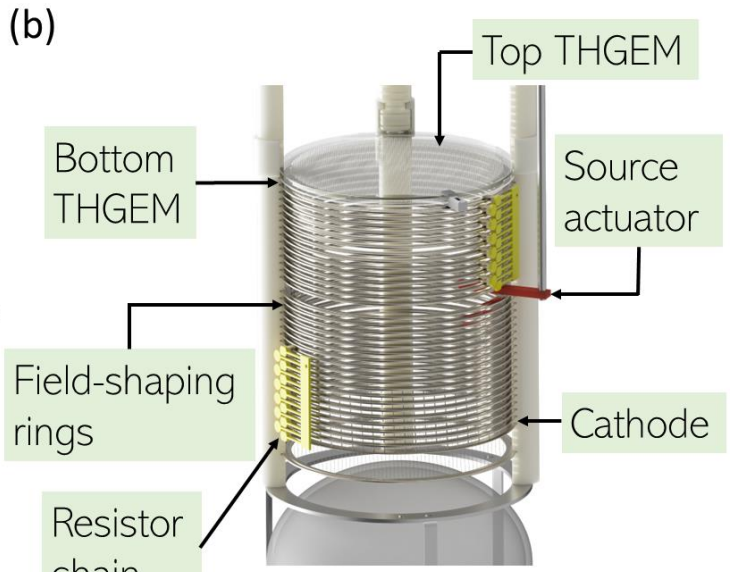
OTPC readout (main topics)

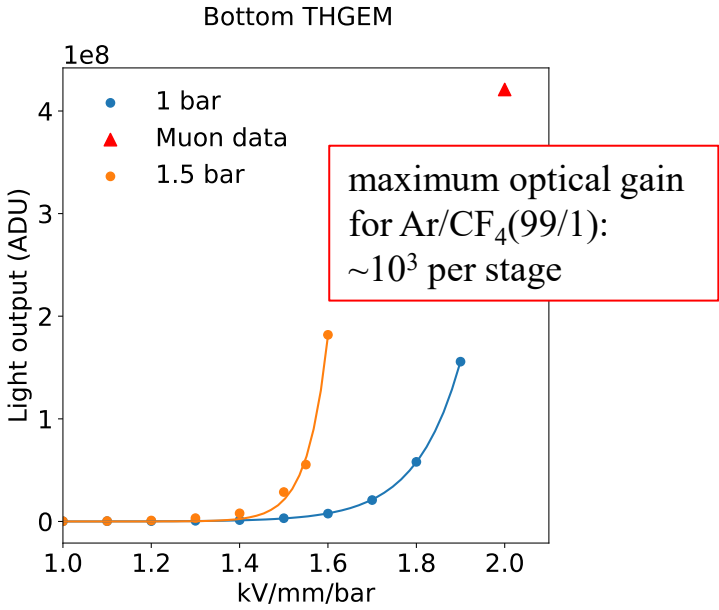


Optical tracking (demonstration at 1bar)

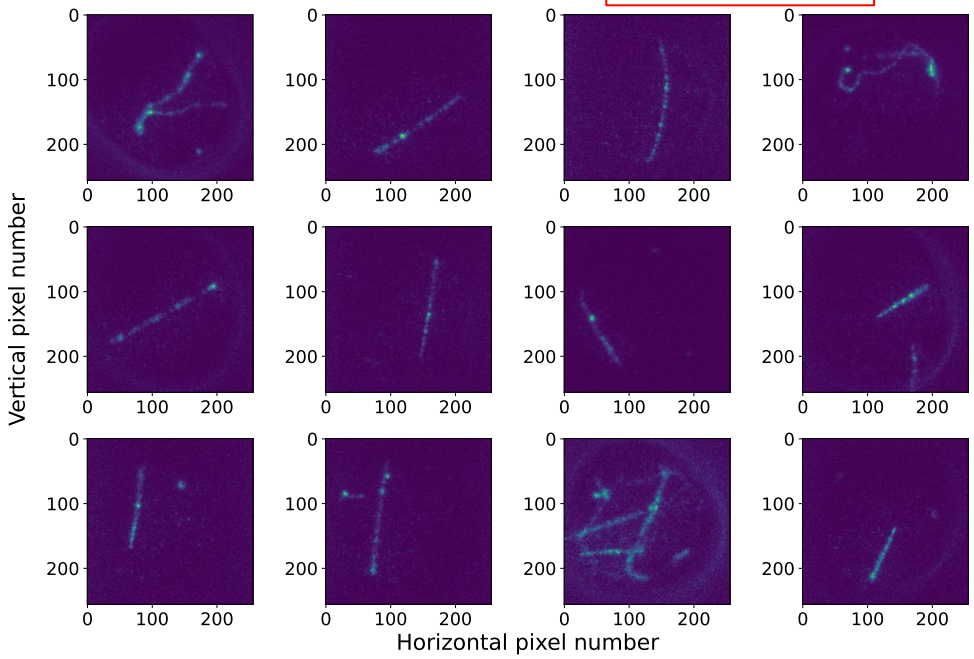
P. Amedo et al.,
arXiv:2312.0503

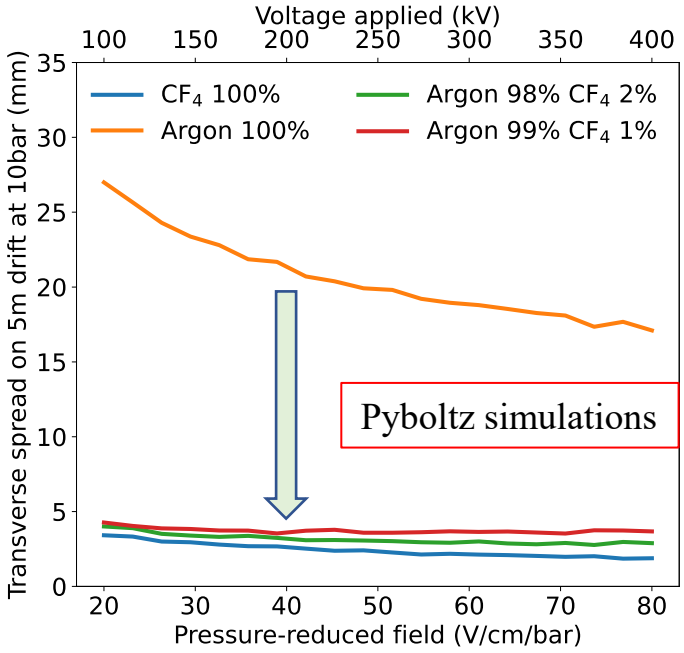






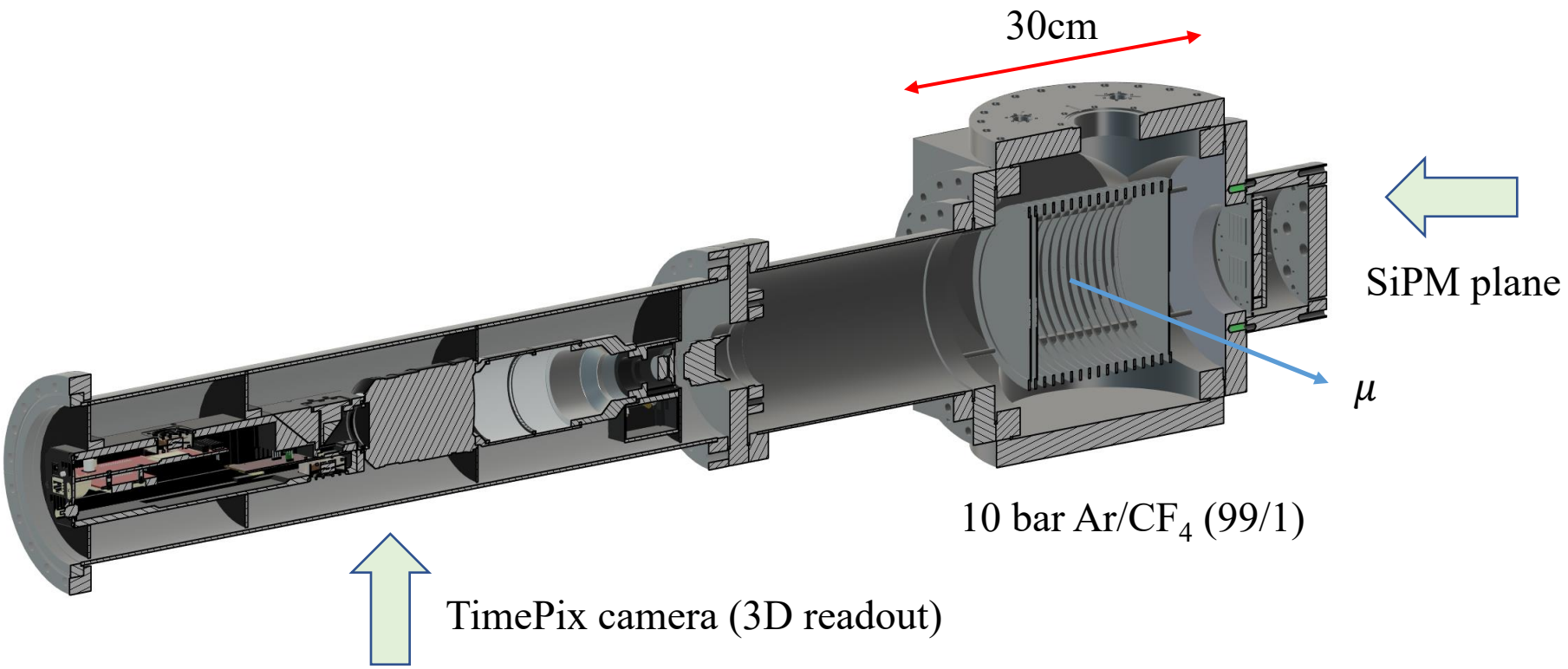
muon gallery





Status of high-pressure technology demonstrator
(Gaseous Argon -$T_{0,}$ **GAT0**)

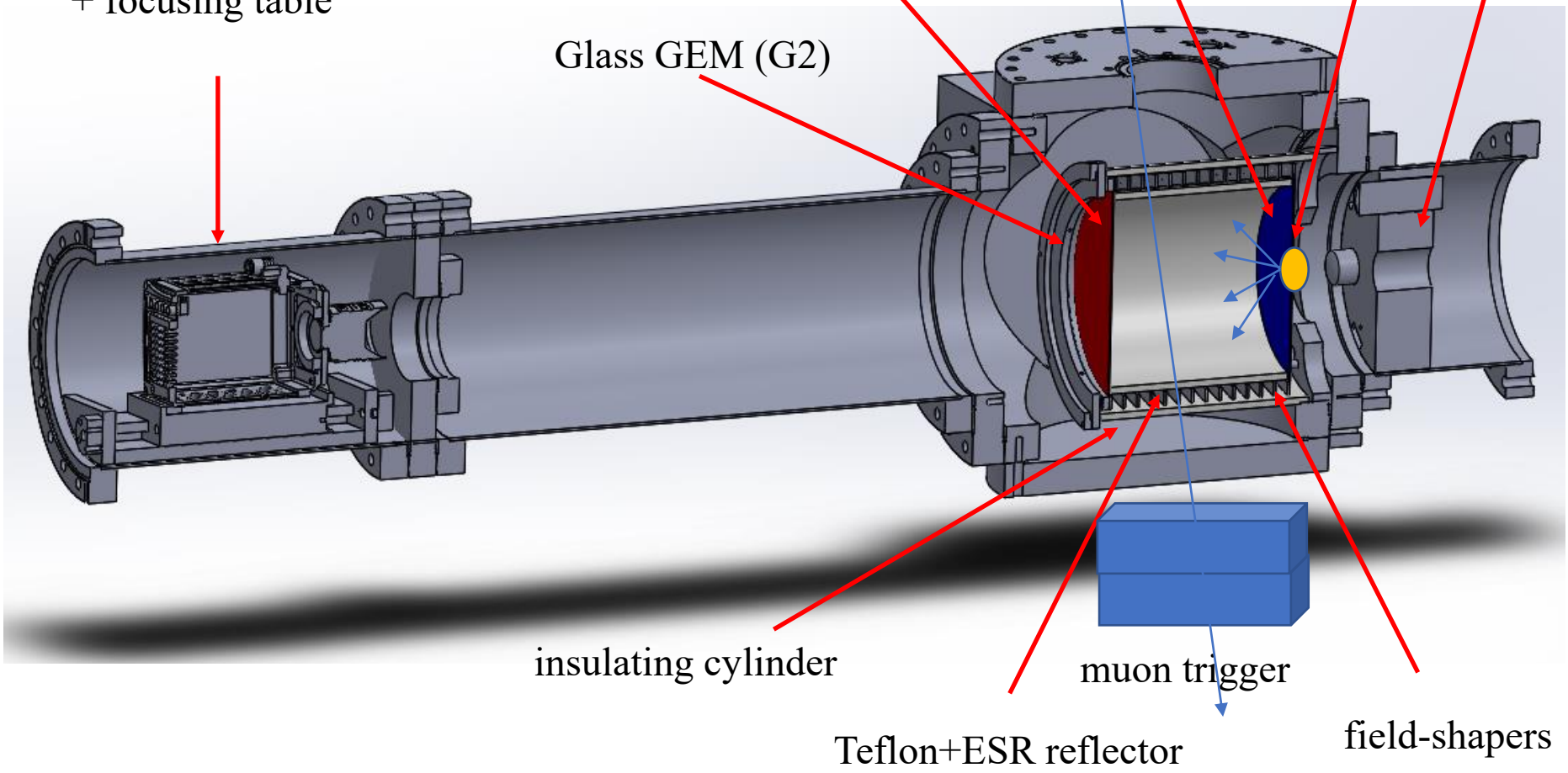
NDGAr-T_0 final demonstrator (under design)



Beamtime foreseen for spring-summer 2025

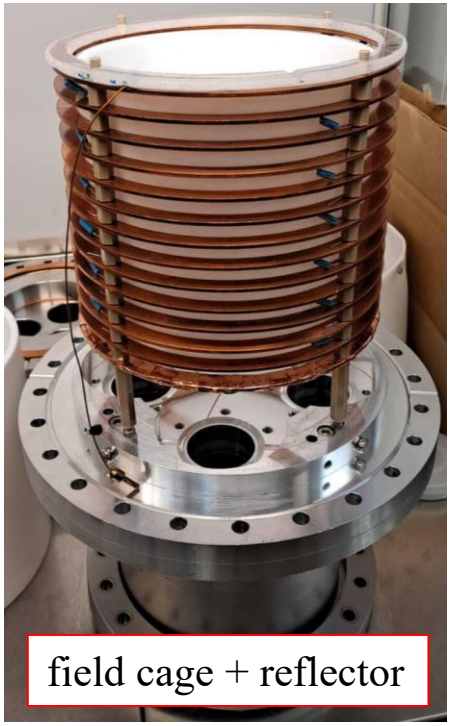
Status of technology demonstrator (phase I)

first results!

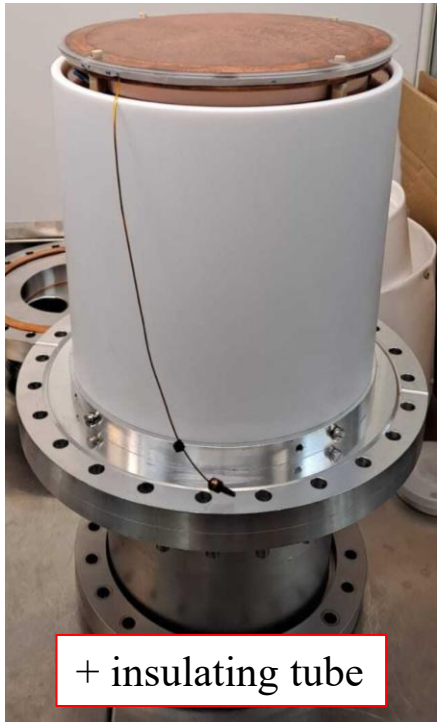


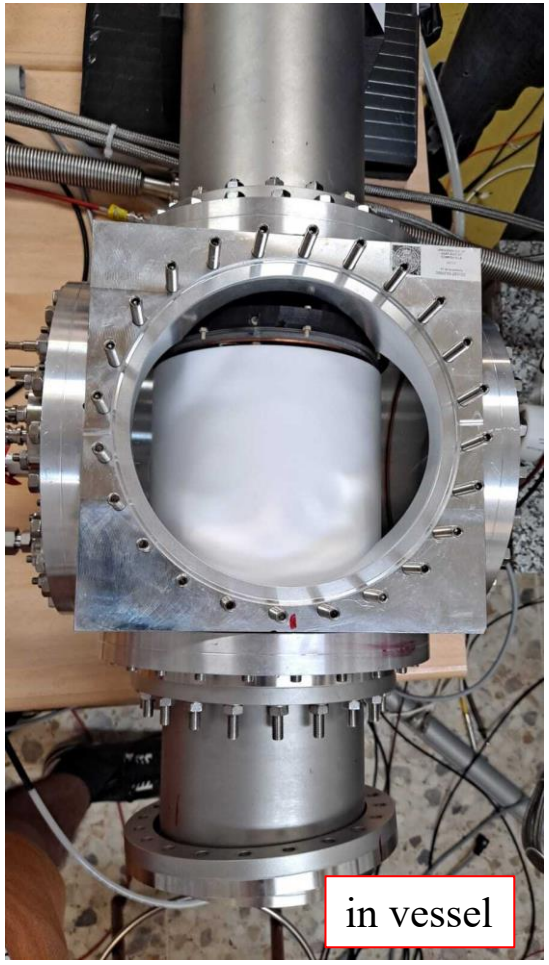
intermediate goal: 2D track readout + PMTs, with cosmics and alphas at 5-10bar

Assembly


field cage + reflector


+ acrylic GEM


+ insulating tube


in vessel

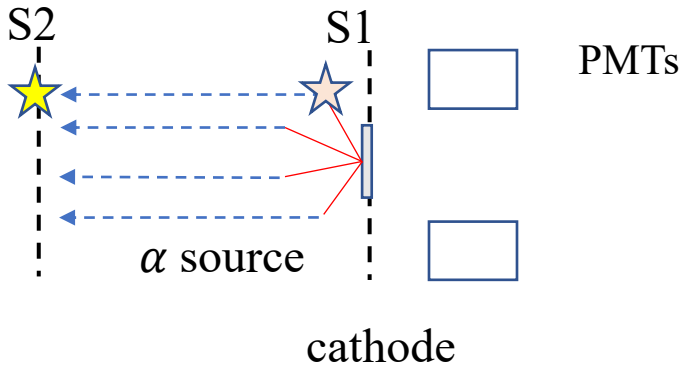

+ glass GEM


(top view)

active region:
~15 cm height,
15 cm diameter

First S1 results

(Ar/CF_4 at 99/1, 1bar)



S1 visible in all PMs! (more than 4 phe/5MeV, without detailed analysis)

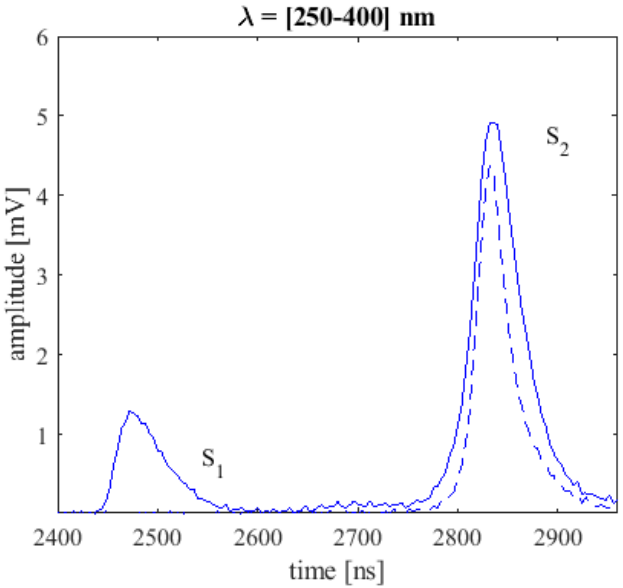
Appendix

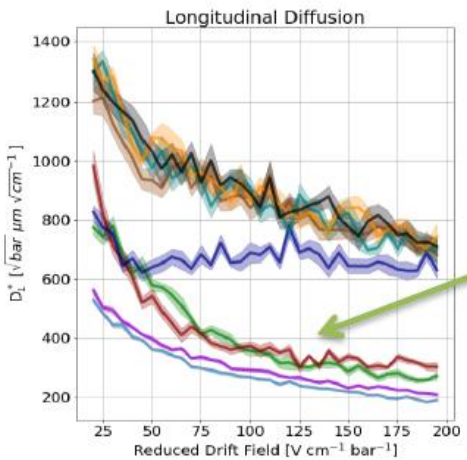
The path towards gas…

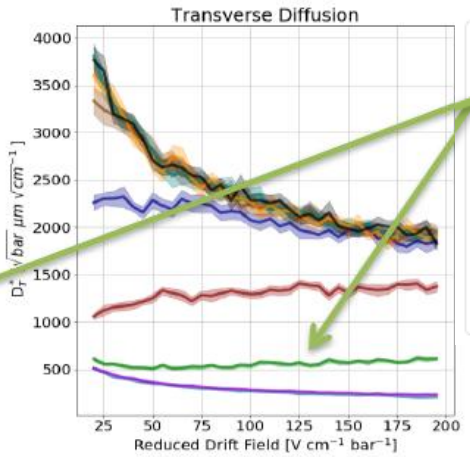
- Ionization density is about x 50 less in gas. Requires additional multiplication!.
- Diffusion is at least x10 larger than in liquid. Requires using molecular additives!.
- Conventional TPC additives eliminate scintillation (‘quenching’)!.

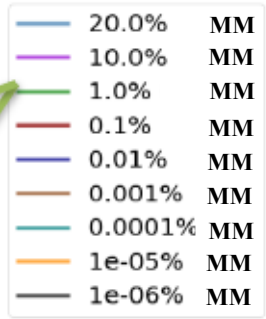
2% CH_4 (V_a =3600V) ← conventional additive

MM (V_a =3300V) ← wavelength-shifting additive



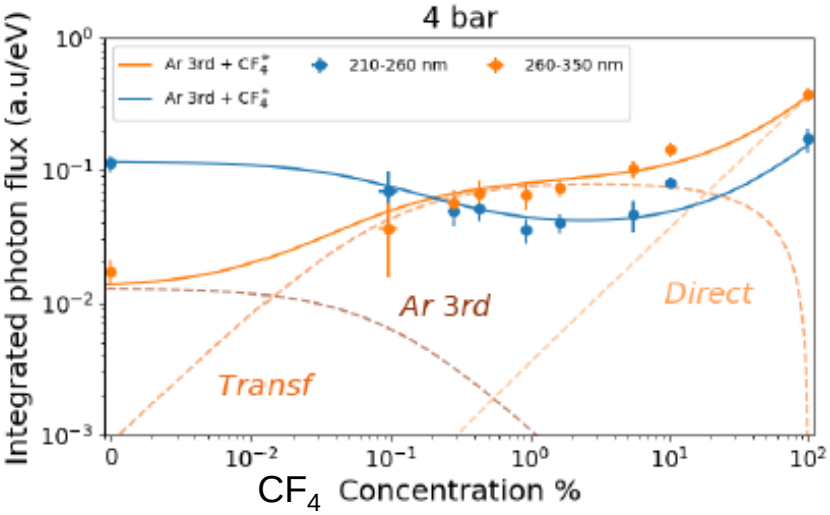


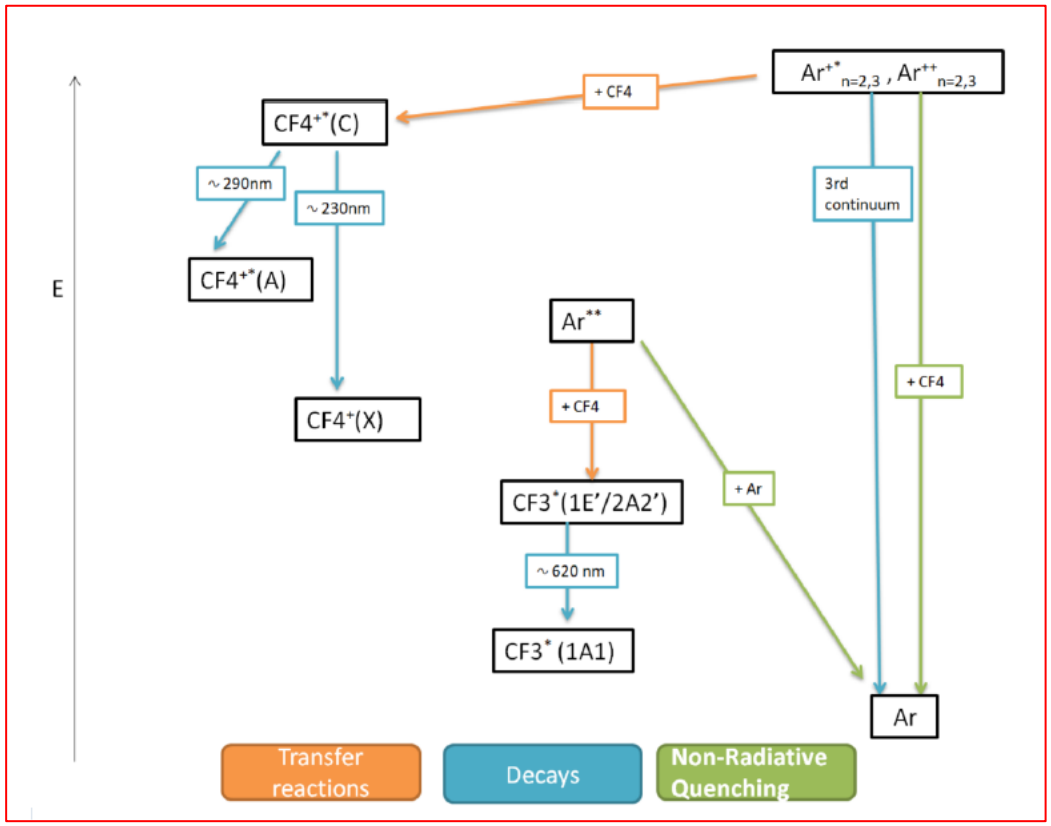




Primary scintillation in Ar/CF_4 (II)

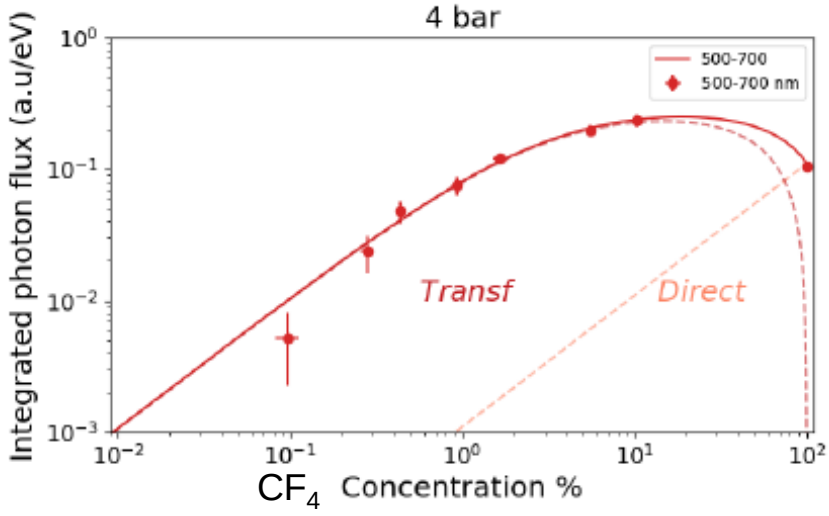
emission in UV



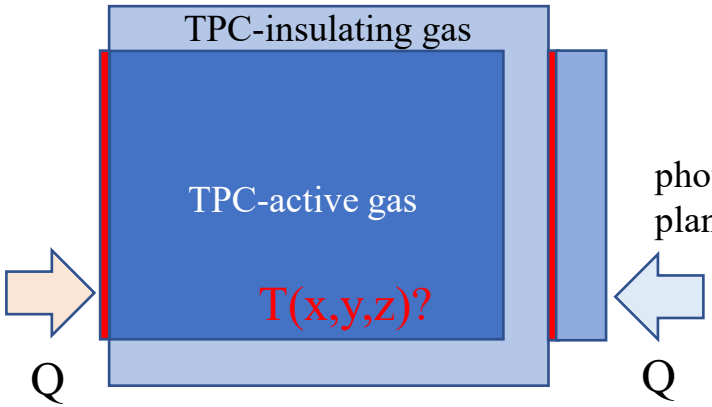


kinetic model
(2 parameter per band)

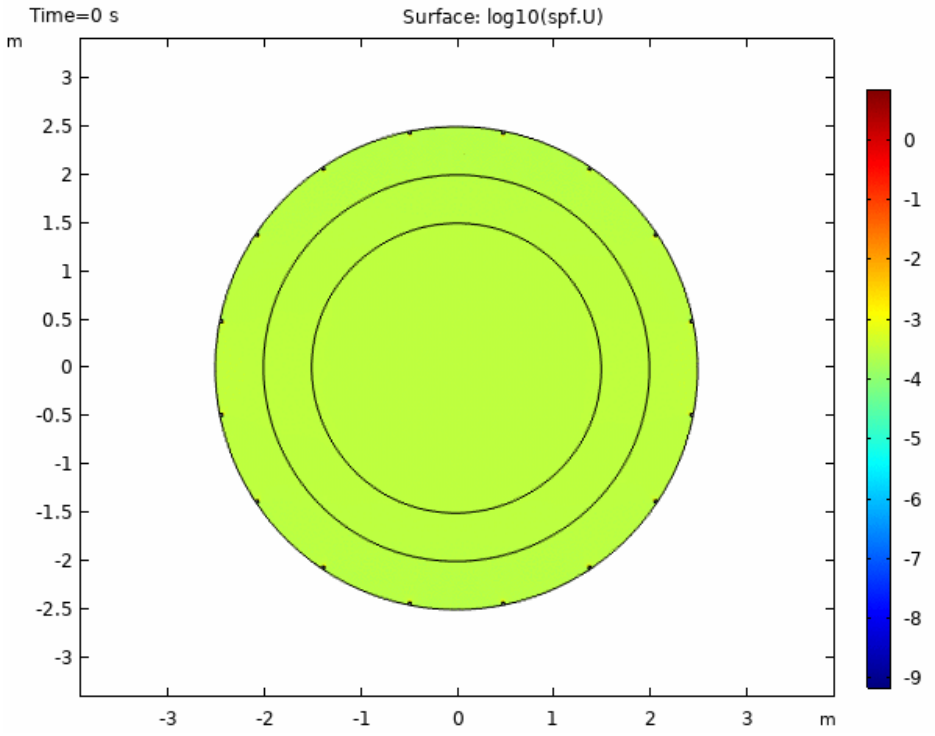
emission in visible



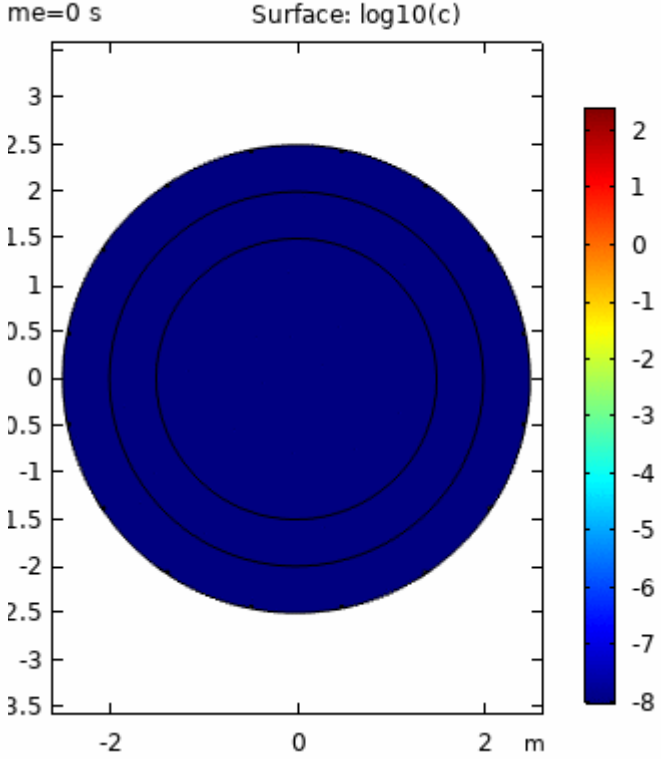
Active cryostat (integration)



minimizing temperature gradients is crucial for stability of drift velocity and impurity distribution



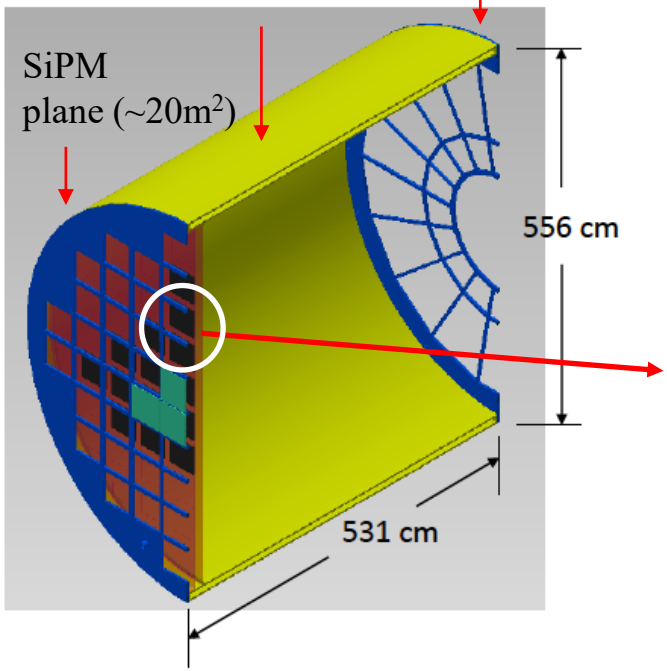
velocity field (log)

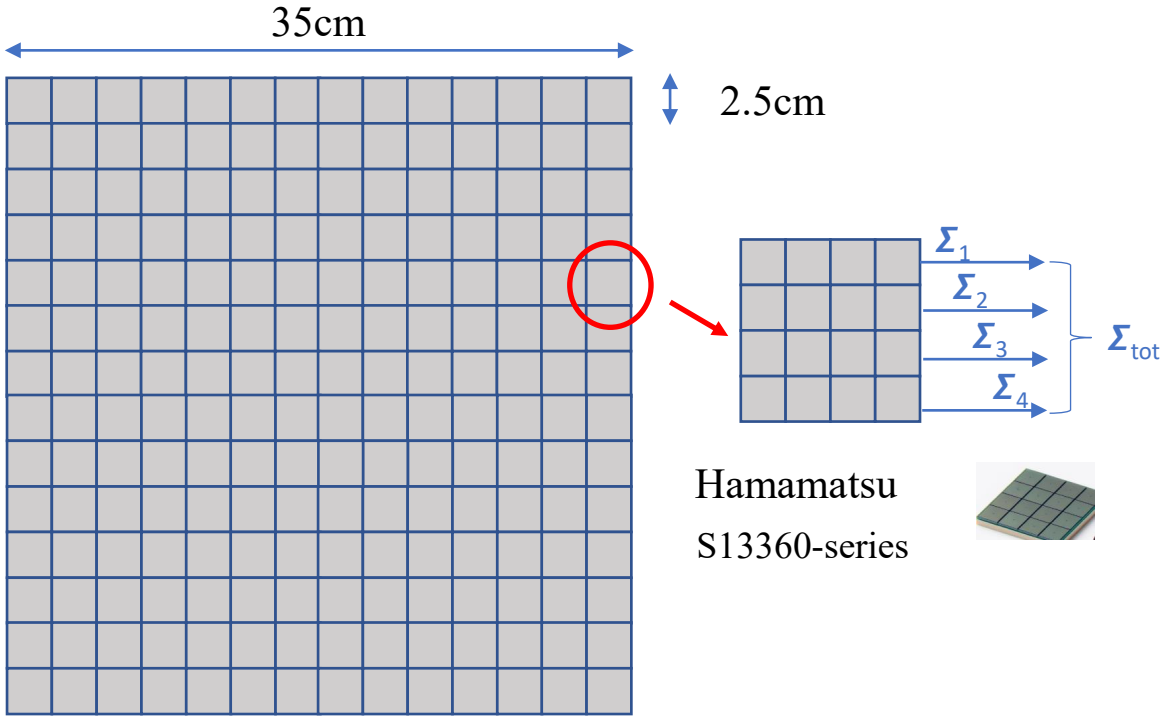


impurity concentration (log)

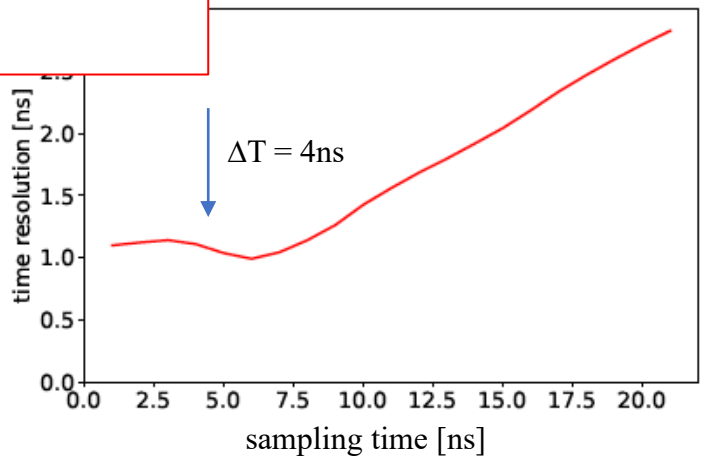
(just an example of ongoing activities, 3D simulations in progress)

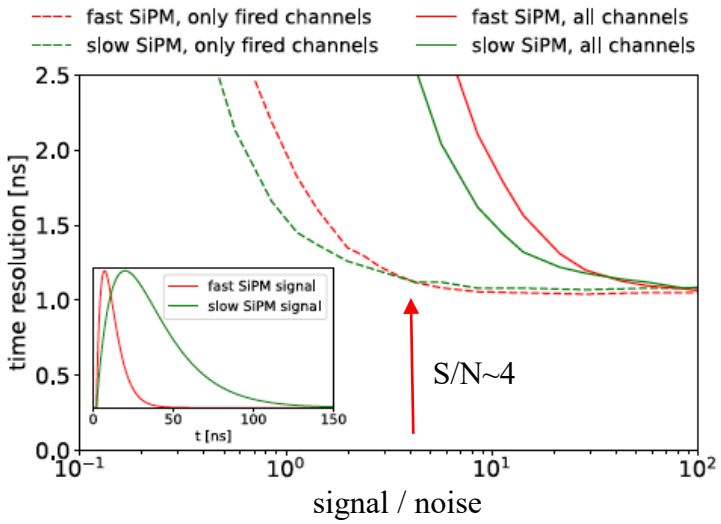
Proposed readout scheme





- ~ 125-150 modules in cathode plane.
- ~ 256 tiles per module.
- ~ 16 SiPMs (6*6mm²) per tile.
- ~ 32000 readout channels.



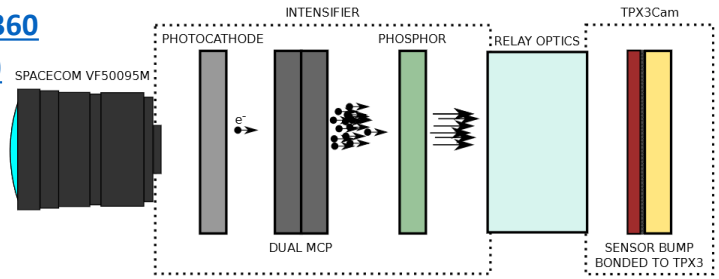


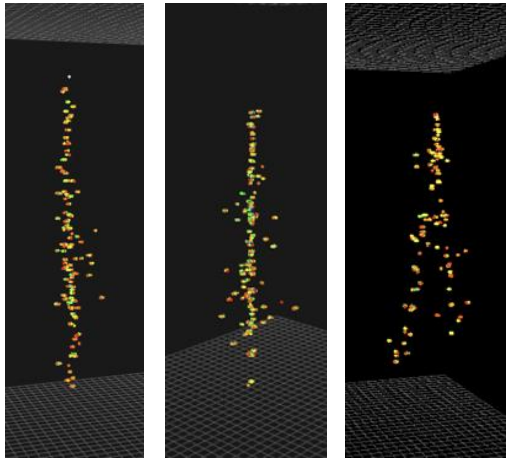
P. Amedo[3], D. González-Díaz[3], A. Lowe[1], K. Majumdar[1], K. Mavrokoridis*[1], M. Nessi†[2], B. Philippou[1], F. Pietropaolo[2], F. Resnati[2], A. Roberts[1], Á. Saá Hernández[3], C. Touramanis[1] and J. Vann[1]

[1] University of Liverpool, Department of Physics, Oliver Lodge Bld, Liverpool, L69 7ZE, UK
[2] European Organization for Particle Physics (CERN), Geneva, Switzerland
[3] Instituto Galego de Física de Altas Enerxías (IGFAE) Rúa de Xoaquín Díaz de Rábago, s/n, Campus Vida, 15782 Santiago de Compostela, Spain

Breakthrough in LAr TPCs!

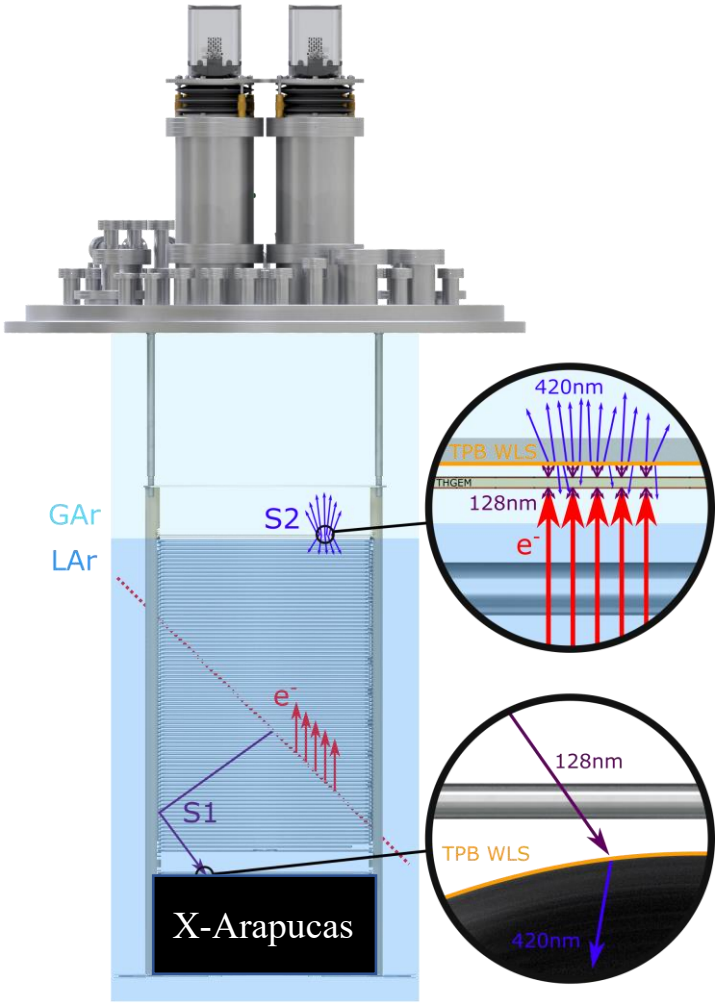
CERN LOI: https://cds.cern.ch/record/2739360
https://doi.org/10.48550/arXiv.2301.02530



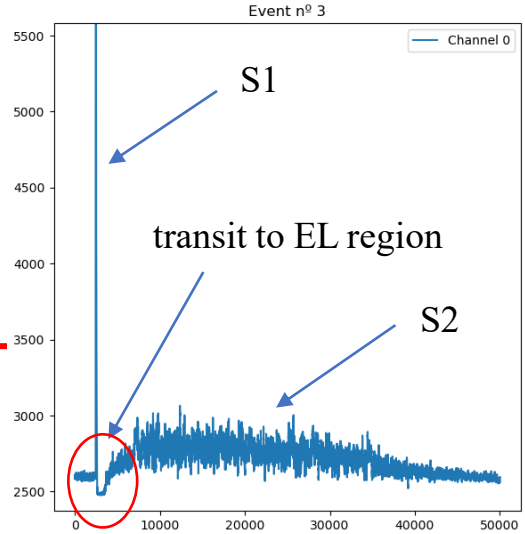


TPX3Cam

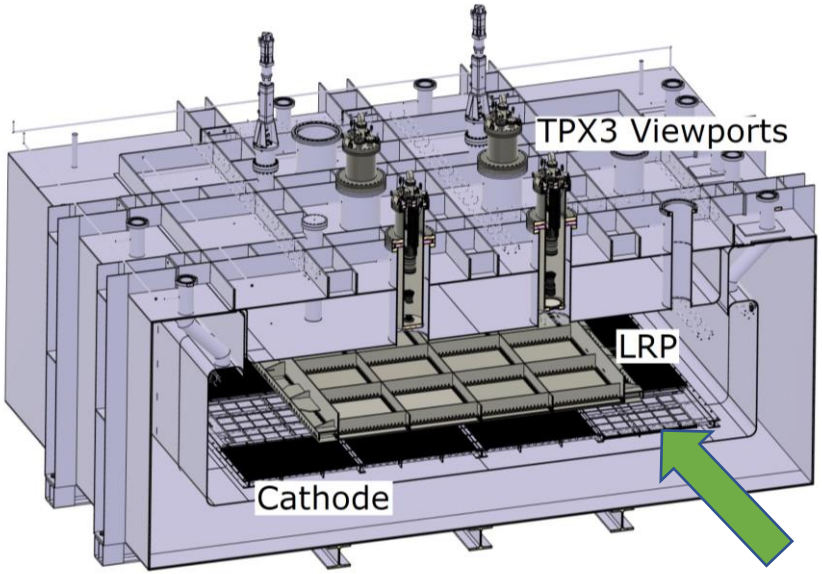
- Raw data is natively 3D. Just need to convert ToA to z position using known drift velocity in the TPC and (x,y) pixel number to mm using the know field of view of the lens.
- Huge readout rates are possible (80MHits/s)
- Zero-suppressed readout comes for free (~few KBytes per event)
- Relies on Timepix sensor
- Comparatively low cost
- Same readout is possible for dual-phase and gas TPCs



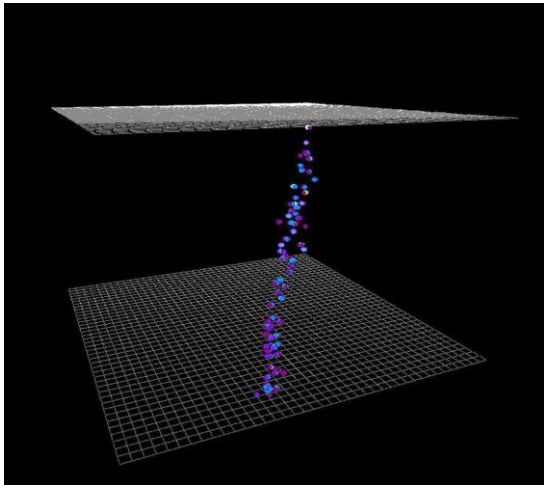
X-Arapucas



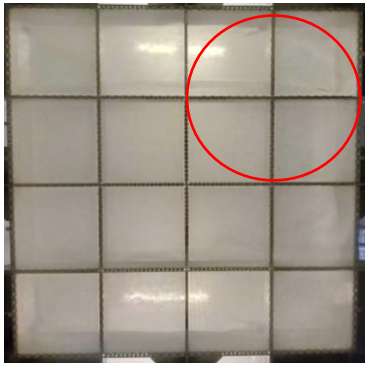
TimePix cameras



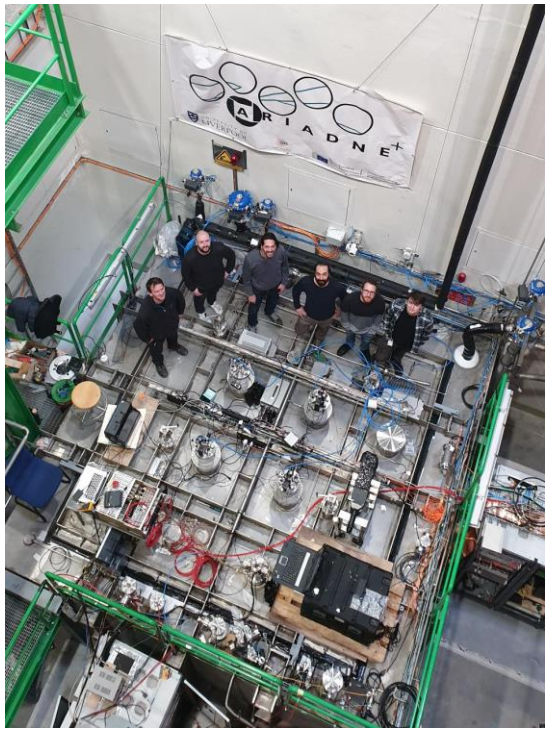
3D optical imaging!!
(a unique feature of ARIADNE)



~1m^2 field-of-view



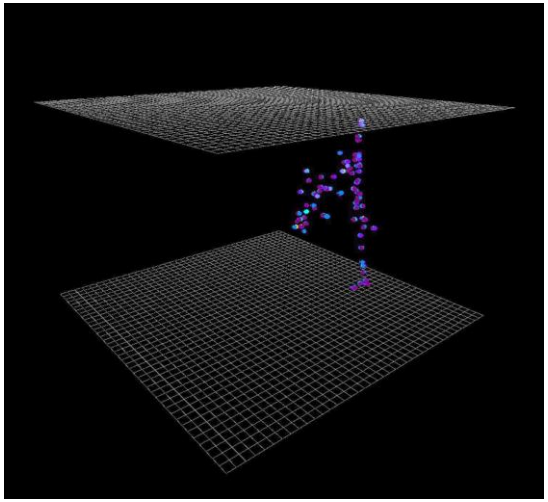
2m^2 glass GEMs



1x1m^2 -> Δ_x = 4mm

0.5x0.5m^2 -> Δ_x = 2mm

(80 TimePix cameras in ND-GAr)



analysis ongoing!

TPX3Cams Cost Estimates for a Near Detector

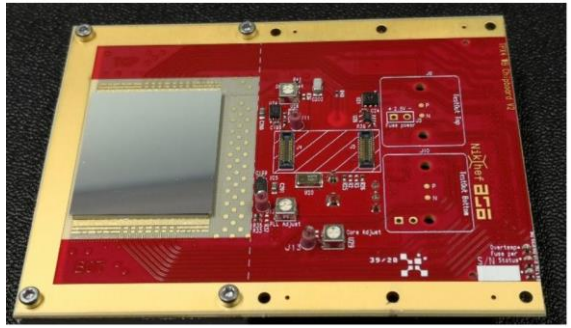
Table: As an example, demonstration figures for use of TimePix within a Dune Near Detector - 16m^2, 4m x 4m

Camera type	Sen. Size (pixels)	Cameras to cover 1m^2	Resolution (mm/pix)	Total cameras (to cover 16m^2)	Total cost (assuming €15k /camera*)
TPX3	256x256	9	1.3 (~ARIADNE)	144	2.1M
TPX3	256x256	4	2	64	0.96M
TPX3	256x256	1	4 (~ARIADNE$^+$)	16	240k
TPX4	512x448	4	1	64	0.96M
TPX4	512x448	1	2	16	240k
TPX4	**512x448**	**0.66 (1.5m/cam)**	**3**	**10**	**150k**

* Cost for a moderate TPX camera production number, therefore higher price than a Far Detector. Intensifiers and optics will double total cost

TPX3 -> TPX4

			Timepix3 (2013)	Timepix4 (2019)	
Technology			130nm – 8 metal	65nm – 10 metal	
Pixel Size			55 x 55 µm	55 x 55 µm	
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448	**3.5x**
Sensitive area			1.98 cm^2	6.94 cm^2	
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA		
		Event Packet	48-bit	64-bit	**33%**
		Max rate	0.43x10^6 hits/mm^2/s	**3.58x10^6 hits/mm^2/s**	**8x**
		Max Pix rate	1.3 KHz/pixel	**10.8 KHz/pixel**	
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)	
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr)	
		Max count rate	~0.82 x 10^9 hits/mm^2/s	~5 x 10^9 hits/mm^2/s	**6x**
TOT energy resolution			< 2KeV	**< 1Kev**	**2x**
Time resolution			1.56ns	**195.3125ps**	**8x**
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	≤163.84 Gbps (16x @10.24 Gbps)	**32x**
Target global minimum threshold			<500 e^-	<500 e^-	



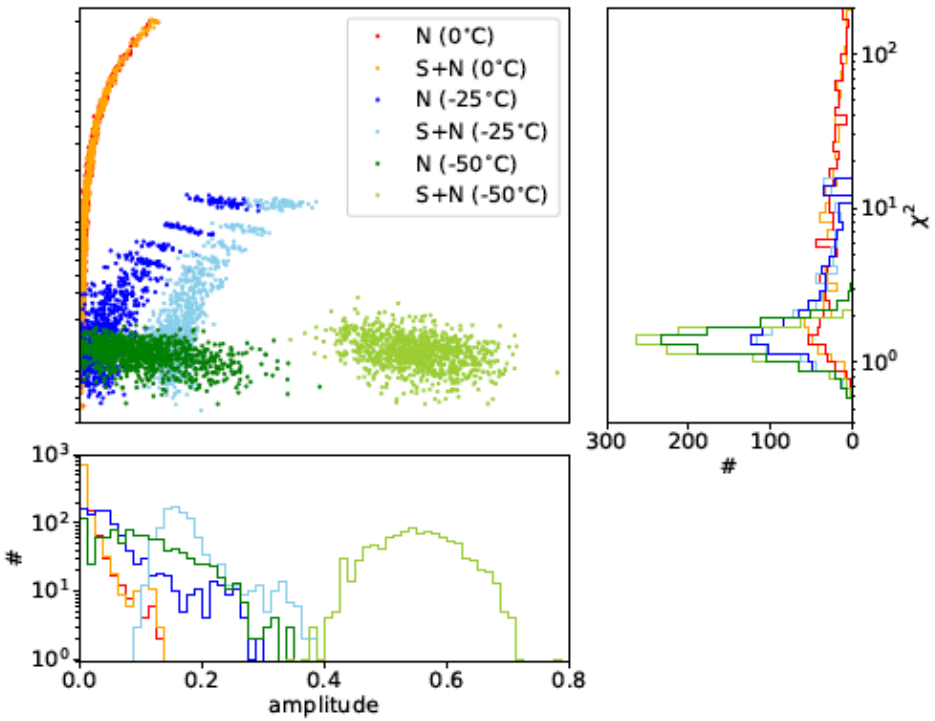


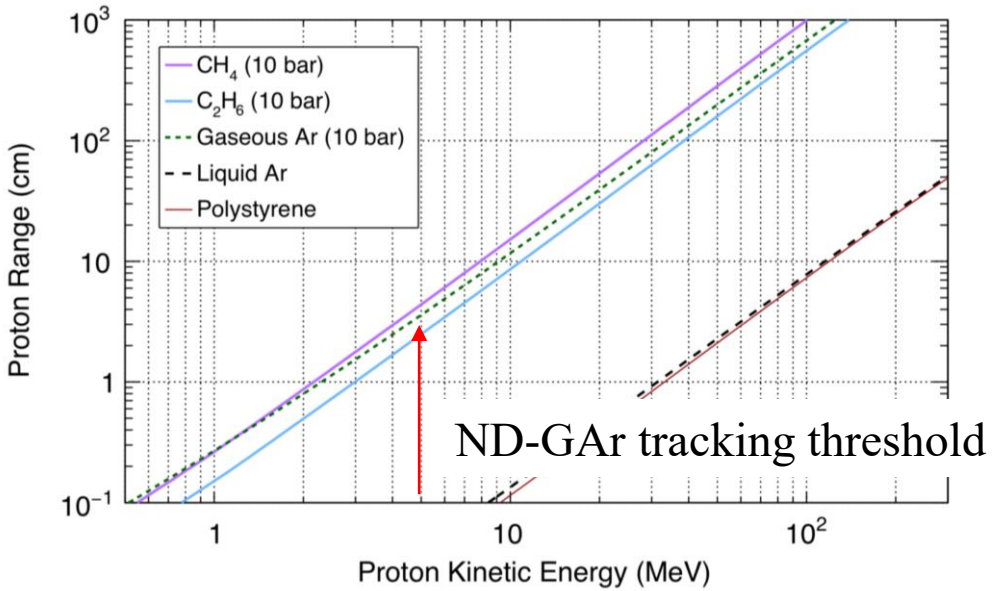
Figure 6. χ^2 vs. amplitude plot for 5 MeV deposits at around mid-chamber, for a Teflon-lined TPC. Different temperatures of the photosensor plane are considered in the reconstruction of 'empty' (N) and 'signal' ($S + N$) events.

Space resolution and space sampling

ALICE focuses on centroid reconstruction (space resolution) above all, and sacrifices space sampling. This is convenient for collider physics, otherwise TPCs would have been hardly viable until recently.

ND-GAr needs both: good space resolution for momentum reconstruction of energetic particles, and good space sampling for reconstructing the topological details of the event.

5MeV proton == 40mm range in Ar at 10bar



much more critical for light nuclear fragments and lower energies

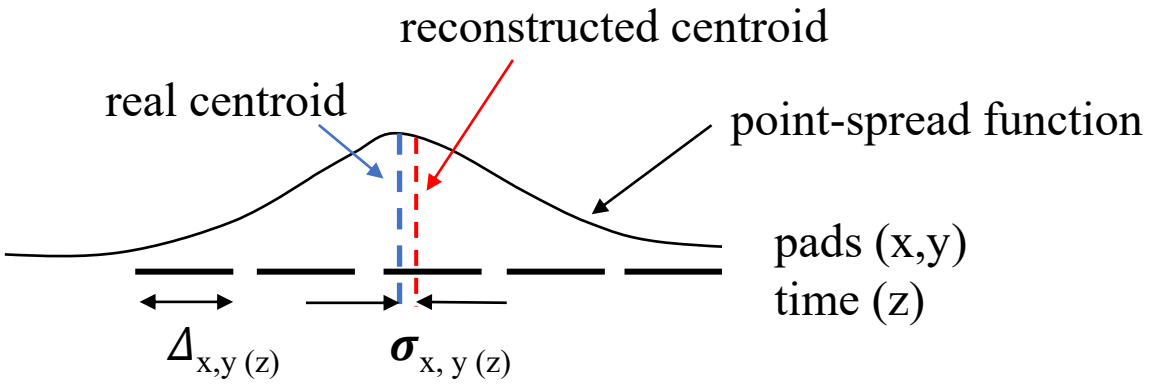
5MeV alpha == 4mm range in Ar at 10bar

Neutrino world vs collider world (round 1: space resolution and space sampling)

space resolution (σ) and space sampling (Δ)

drives momentum resolution

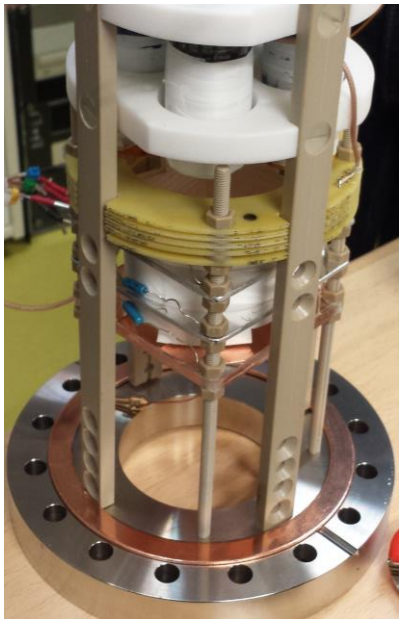
drives tracking threshold, enhanced PID through dE/dx profile, 2-track separation and displaced vertex reconstruction.



ALICE:	σ_x~1mm	Δ_x = 4-15mm	σ_{PSF}~4mm	σ_{diff}~1-2mm/ $\sqrt{m}$
ND-GAr:	σ_x=0.25-1.5mm?	Δ_x = 4-15mm?	σ_{PSF}~4mm?	σ_{diff}~1-2mm / $\sqrt{m}$

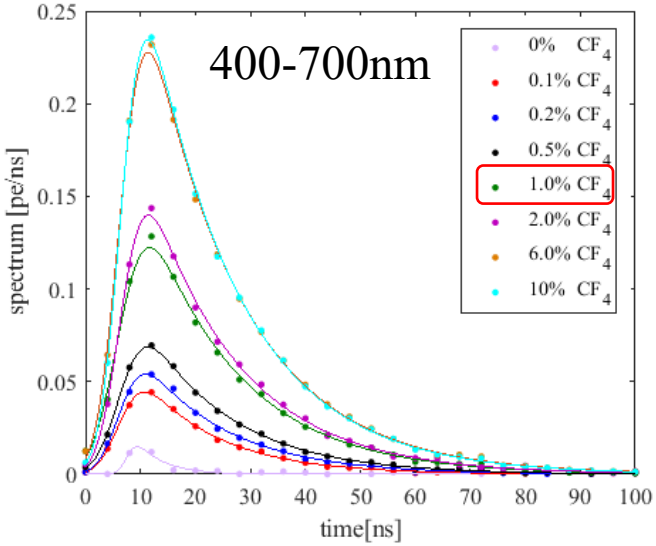
? == is this what we really want/need?

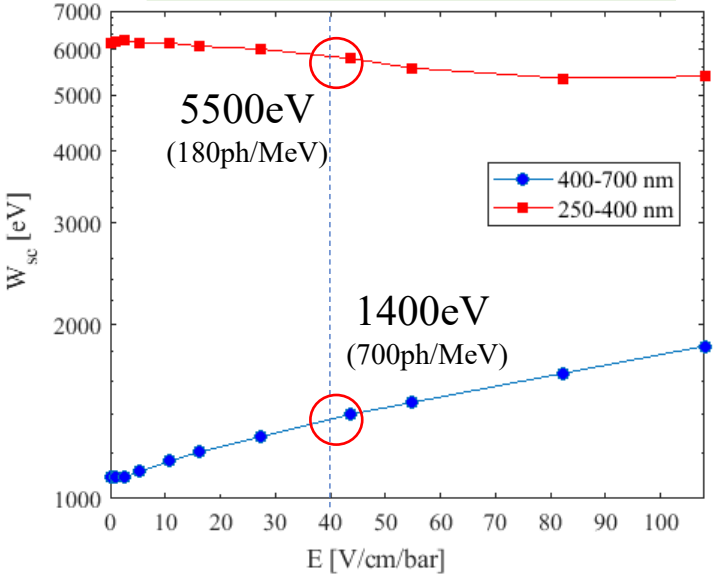
primary scintillation yields and time constants

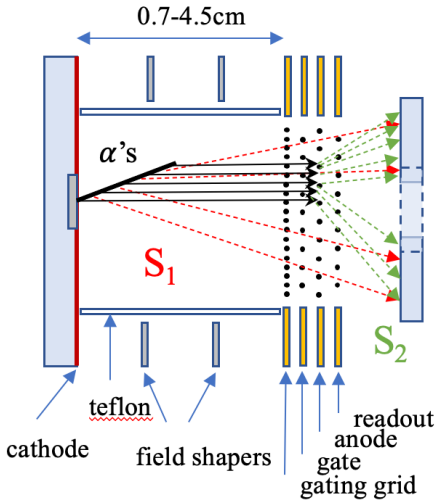


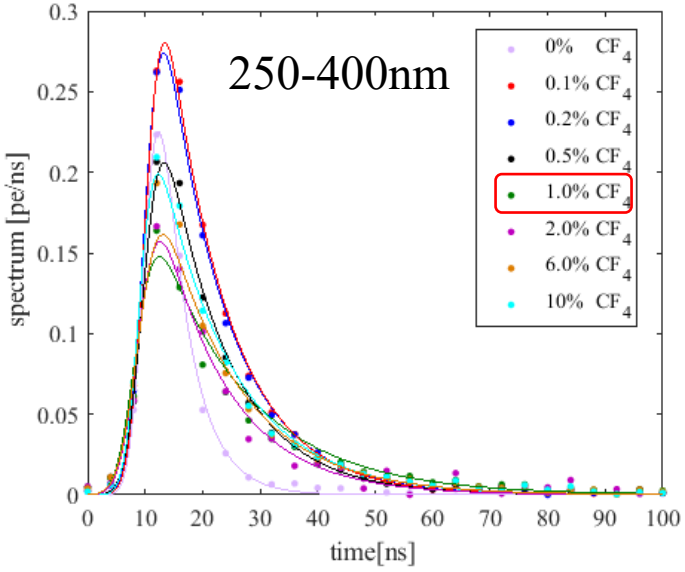
scintillation time profile for α-tracks

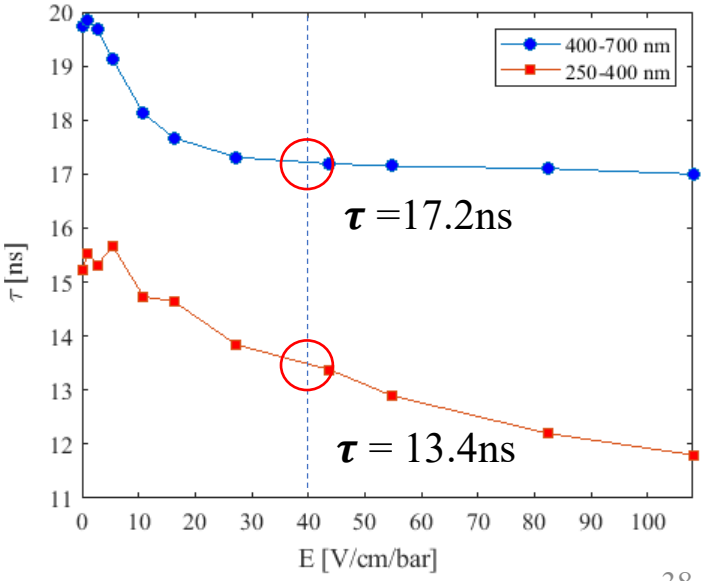
Ar/CF_4 (99/1%) @ 10bar







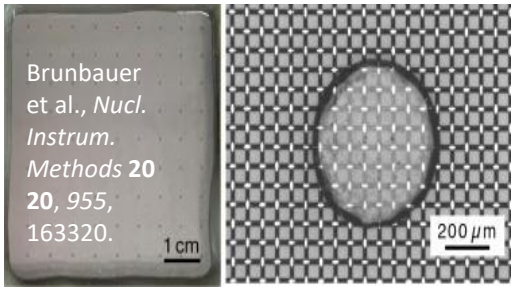




Enabling asset 6: development of structures capable of high optical gain, compatible with S1 (just started)

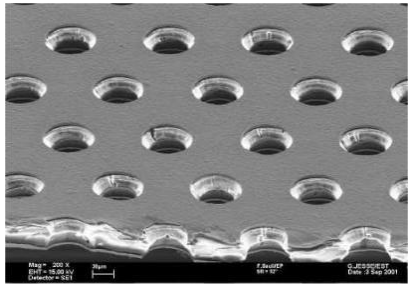
Several multiplication structures (some of them purposely designed for optical readout) have been procured

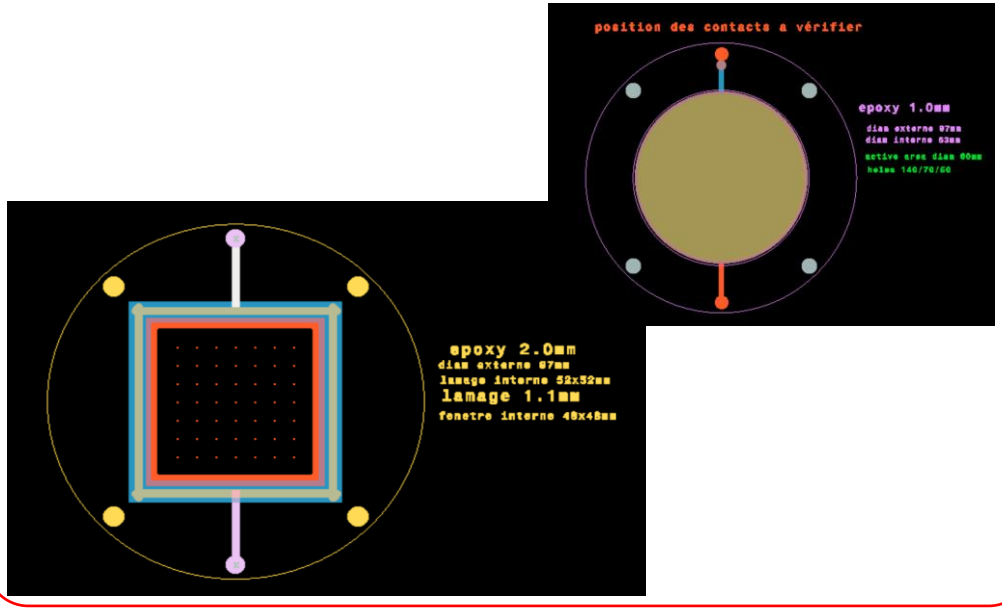
glass Micromegas



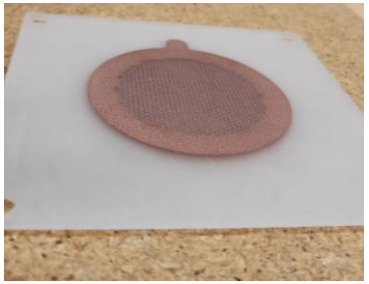
Brunbauer et al., *Nucl. Instrum. Methods* **20** **20**, *955*, 163320.

standard GEMs

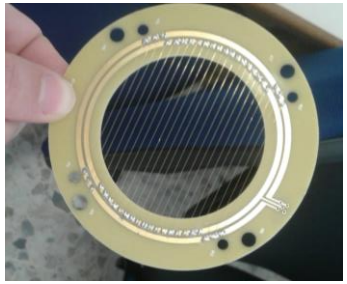




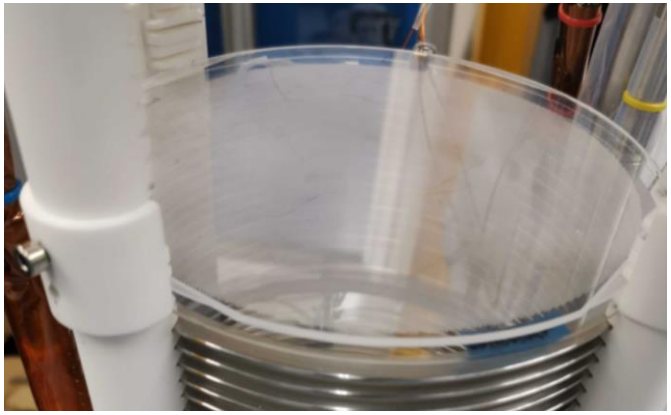
acrylic thick-GEMs



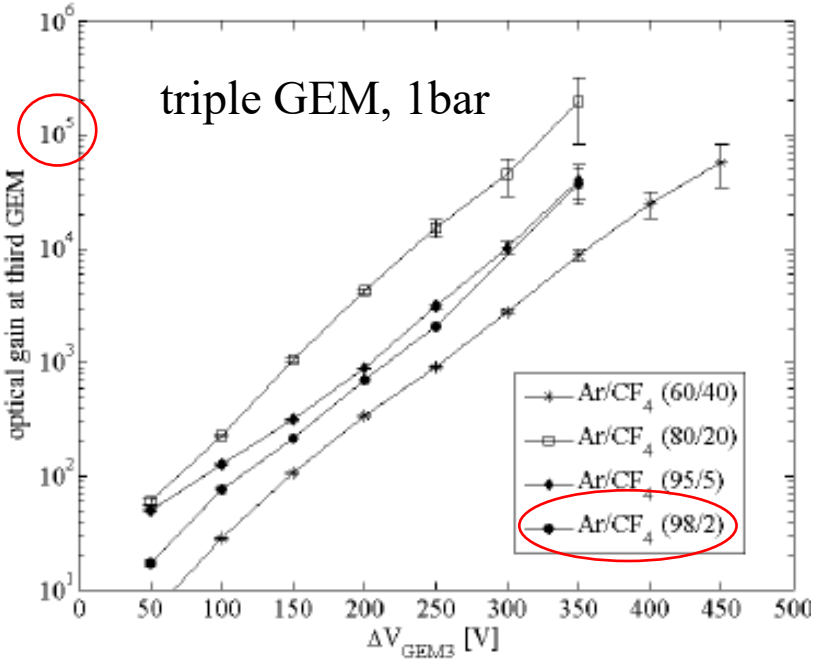
MWPCs

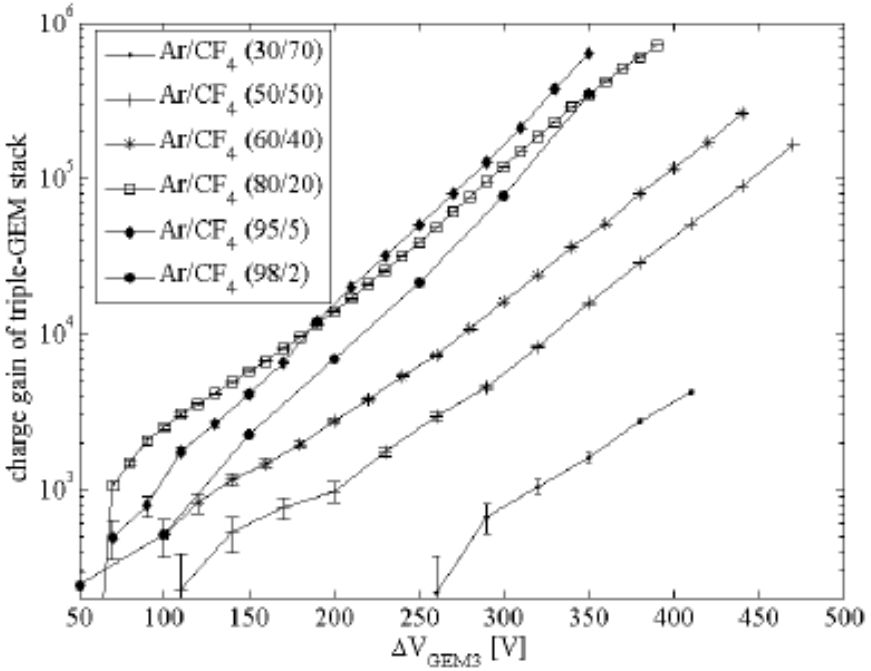


glass GEMs (from ARIADNE)

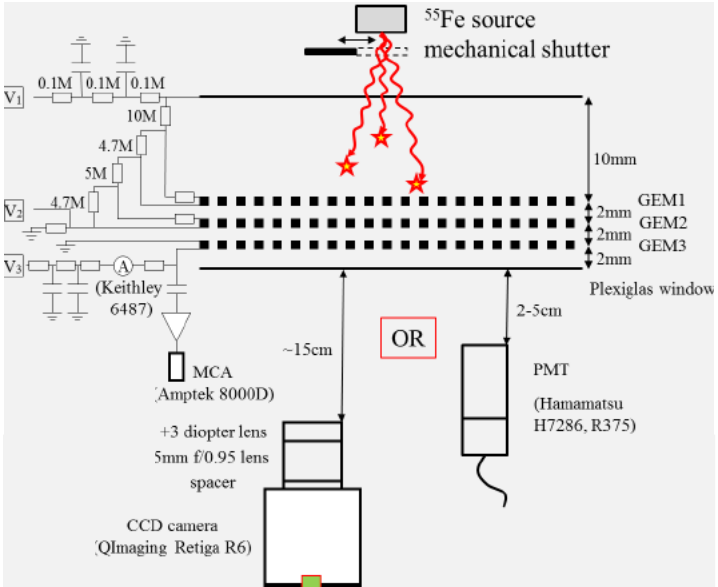


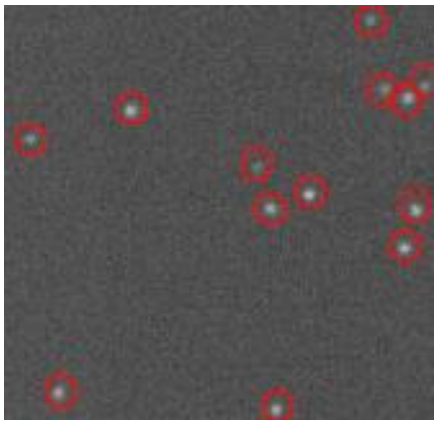
Enabling asset 6: development of structures capable of high optical gain, compatible with S1 (just started)





results obtained at CERN-GDD circa 2017





^{55}Fe x-rays (5.9keV)