Anti-Deuteron identification in Space with Helium calorimeter

(Anti Deuteron Helium Detector)

Preventivi INFN-TIFPA 2023

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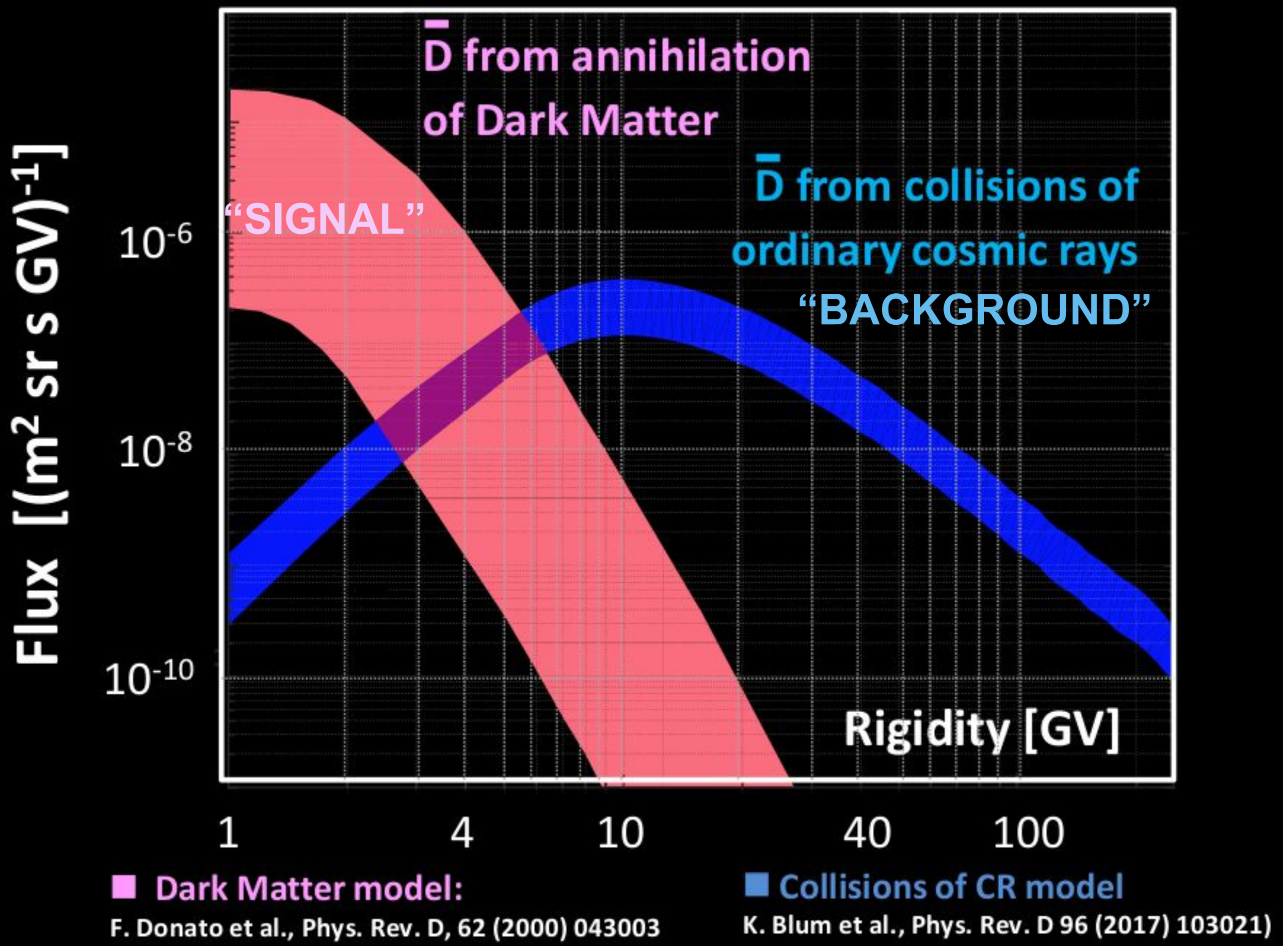
Anti Deuterons in Cosmic rays

Anti Deuterons have been proposed as an almost background free channel for Dark Matter indirect detection



The Anti Deuterons Flux is < 10^{-4} of the Antiproton Flux.

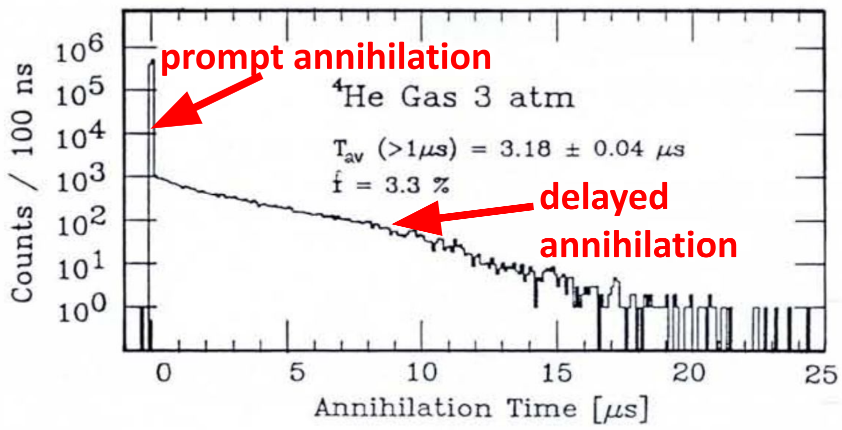
Additional background rejection needed

Helium metastable states

-In matter lifetime of stopped anti-p is ~ps
-In liquid/gas He delayed annihilation: few μs
(~3.3% of the p)(discovered @ KEK in 1991)

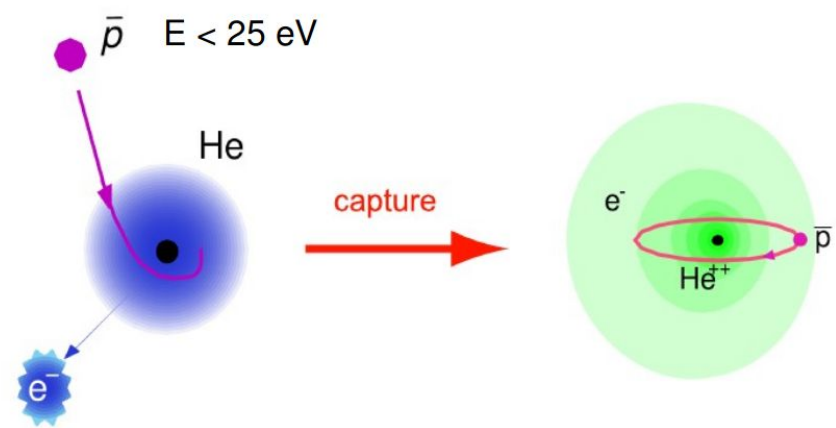
Observed also for K^-, π^- and expected for anti-D

ASACUSA experiment at CERN use these metastable states to measure anti-P mass



THEORY: Phys. Lett. 9 (1964) 65 PRL 23 (1969) 63

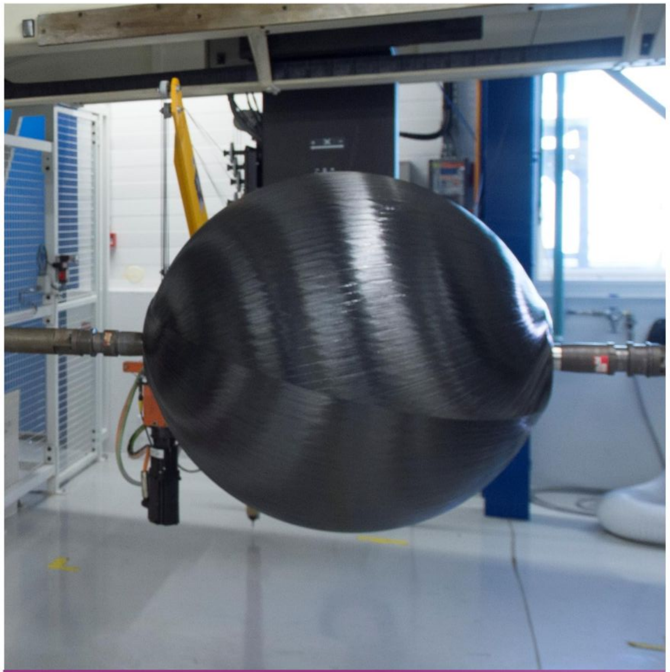
1) The electron is on 1s ground state, while the anti-p (or also π^-,K^-,anti-D) occupies a **large n** level (~38 for anti-p) (~same bounding energy of the ejected e-)
2) the Auger decay is suppressed as well, due to large level spacing of the remaining electron (~25 eV) compared to the small (~2 eV) n→n-1 level spacing of anti-p
3) the remaining electron in anti-p/He suppresses the collisional Stark effect (de-excitation channel for anti-p/p)



a signature for Z=-1 antimatter captures in He is a ~μs delayed energy release

400 bar ⊘ = 90cm Helium tank: space qualified

arianeGROUP

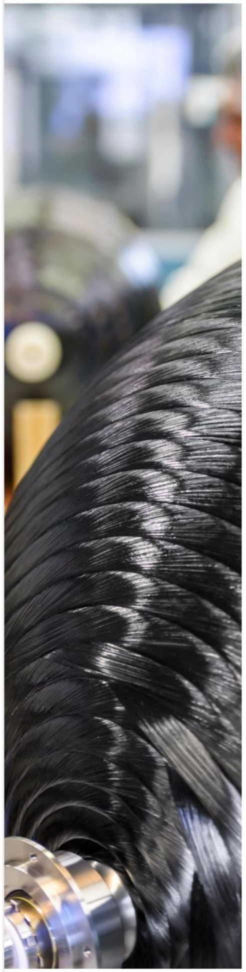


300L HELIUM TANK (MPCV)

HIGH PRESSURE TANKS PRODUCT LINE

- 108L Helium Tank (VEGA)
- **300L Helium Tank (MPCV)**
- Thermoplastic Liner Tank

Can be used for both applications, satellite or launcher.



300L HELIUM TANK (MPCV)

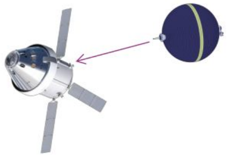
Application: Satellites & Launchers

ArianeGroup has developed and is qualifying a 300 Liters high pressure tank for MPCV (Multiple Purpose Crew Vehicule). This pressurant tank can also be used on launchers.

Characteristics	
Volume	300 Liters
MEOP	Bar 400 Safety factor 2
Burst pressure	> 800 bar
Mass	81 kg (without fixations)
External Diameter	865 mm

Our product:

- **Helium** Storage 300 L
- Developed from **Ariane 5** tank for ATV
- **Polar** Mounting
- **Manned flight** qualified (NASA)
- **ATV** : Flight Proven : (20 Tanks delivered)
- **MPCV :** Under Qualification (flight planed in 2019)



Our activities are environmentally-friendly

©ArianeGroup / SYLVAIN CAMBON / 2018

A UNIQUE EXPERTISE TO SERVE OUR CUSTOMER NEEDS

- Customized solutions : gas, size, MEOP and interface
- Optimized for customers needs : mass, cost, safety and reliability
- ArianeGroup delivered more than 900 tanks without any failure

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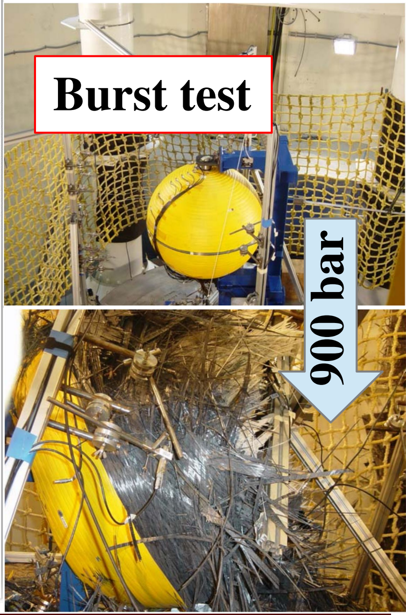
France
www.ariane.group

P = 400 bar
∅ = 87cm
M_{vessel} = 81kg
3.5g/cm^2
M_{He}/M_{tot}=20% @400bar

Stored energy in the gas is ~14kg of TNT

a standard gas bottle would require >1cm of steel for such a size/pressure



Composite overwrapped pressure vessel (COPV)

Current typical application: H_2 storage tanks for automotive

Cylinders must be **light**

Faber relies on a unique +40 year track record which include a very comprehensive range of all Types of Cylinders (Type 1,2,3,4), eachone standing out for superior lightness, reliability and safety. The entire production process is controlled by Faber and performed in-house in one of our own dedicated plants. This ensures that Faber is capable of offering the right cylinder at a price that best fits the needs of our customers.

Faber company

(150km from Trento)

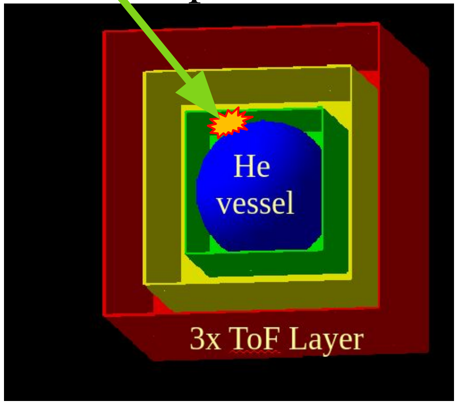
MC exercise with a SIMPLE geometry ⌀ = 90cm: Anti Deuteron He Detector (ADHD)

Preliminary Geant4 simulation:
Detector size: External ToF L = 1.5m;
ToF = 110 kg (4mm scintillator thickness)

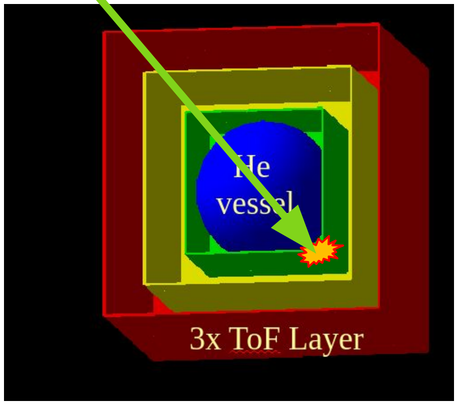
Vessel: ArianeGroup 300L@400bar = 100kg
$M_{He}/M_{detector}$= 10% (very naive, no structure here)

Kinetic energy range: 50-150 MeV/n
(threshold due to energy loss in vessel/ToF)

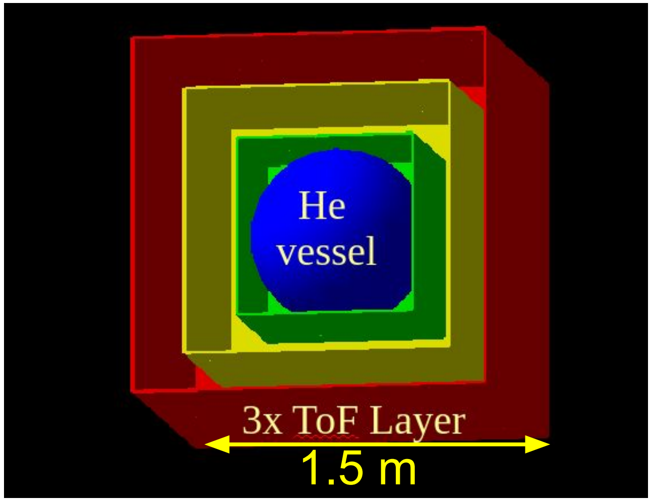
50MeV/n
stop in the vessel



150MeV/n
cross the Helium

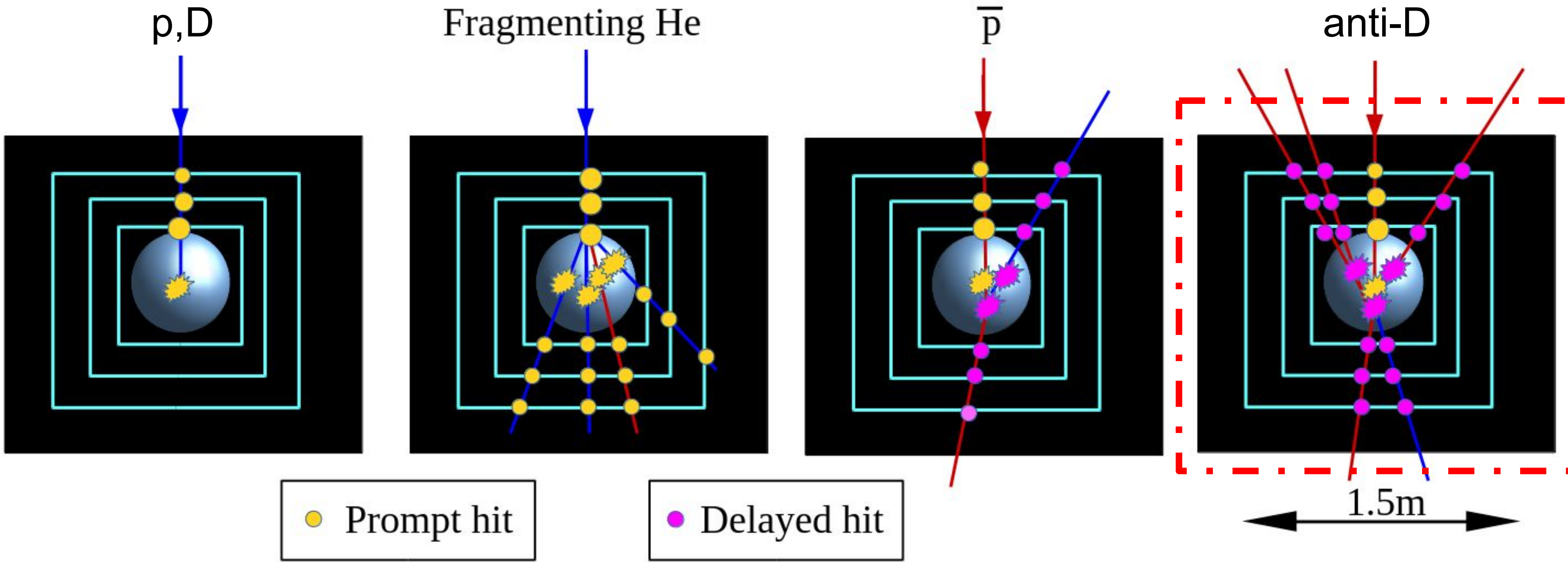


Simple Concept:
HeCalorimeter (scintillator)
3xTime of Flight (segmented) layers



We need a light/thin vessel but we also want high Helium pressure and large vessel volume.
This imply a large force on the vessel walls and this is the main weakness of the ADHD concept.

MC exercise with a SIMPLE geometry: Particle Identification



SIMPLE TRIGGER implementation:

A MIP release 12 MeV crossing HeCal diameter

1) Prompt HeCal Energy > 10MeV (reject MIPs)

2) only 3 prompt ToF hits (reject not stopping)

3) Delayed HeCal Energy >10MeV & <10µs (reject protons or nuclei stopping in HeCal)

AntiProton background rejection:

4) β_{ToF} vs HeCal E_{prompt}

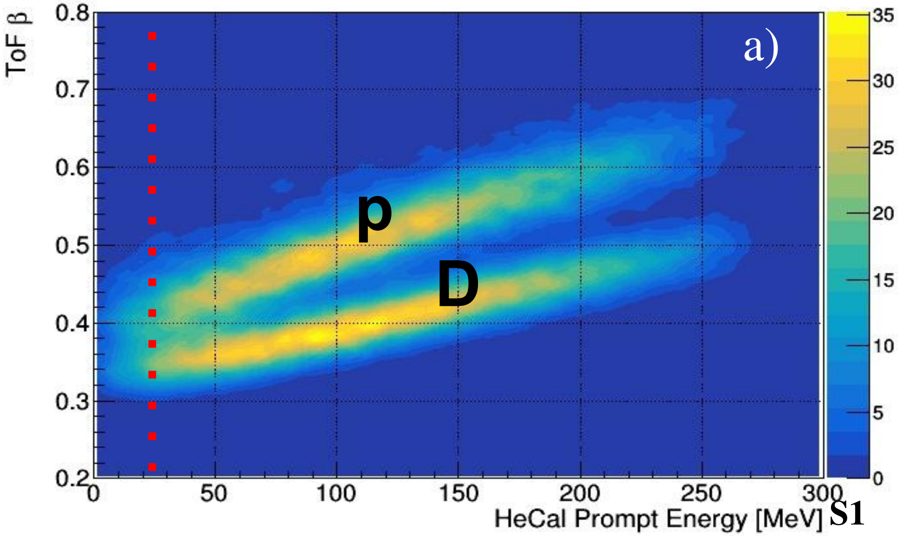
5) dE/dx ToF vs HeCal E_{prompt}

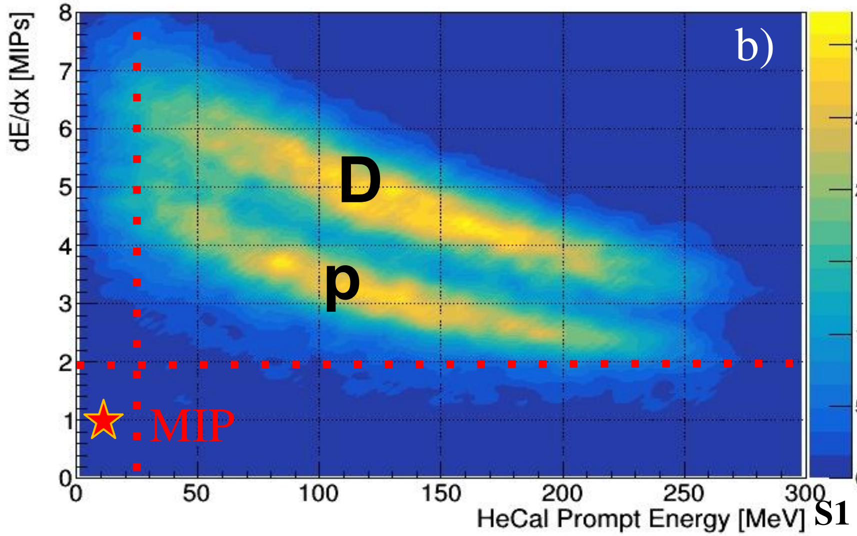
6) event topology (>3 delayed tracks)

7) HeCal E_{delay} > 350 MeV

anti-p/anti-D separation: prompt signal

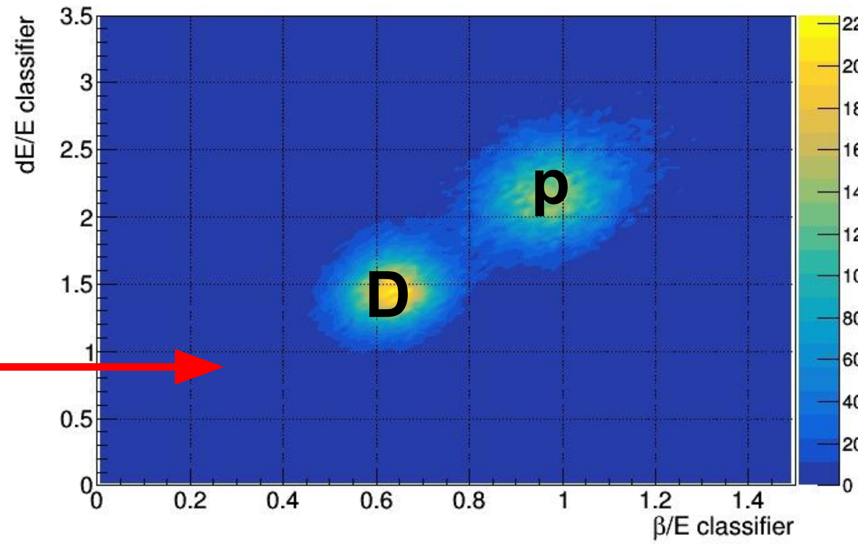
★ MIP (β=1)





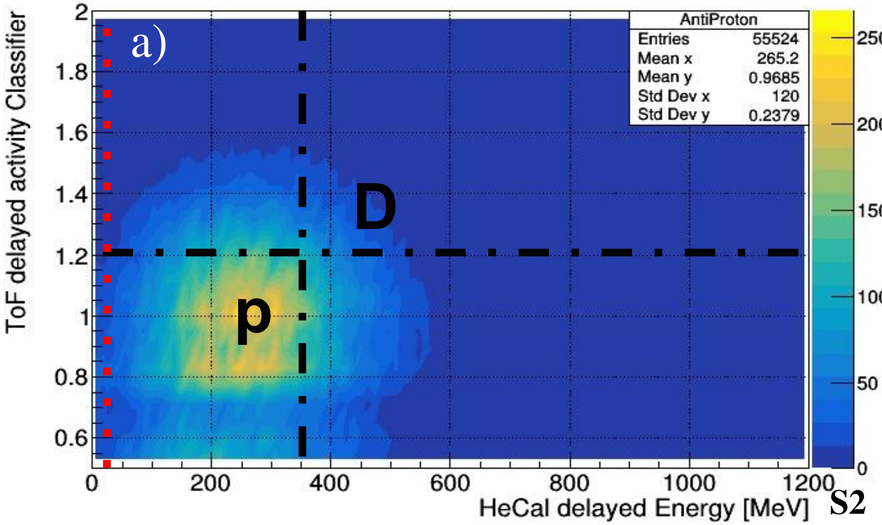
ToF (30cm baseline & 4mm thickness):
β resolution 5% => $\sigma_{x/y}$ ~few cm & σ_T<0.1ns
- ToF Energy resolution: 10%
- He Calorimeter Energy resolution: 10%

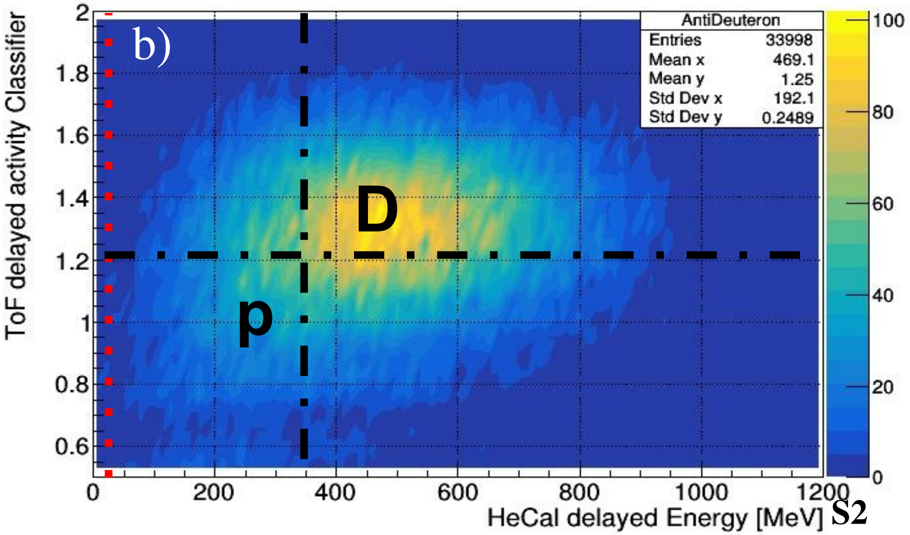
Parametrization of (**β** vs *E)* & *(dE/dx vs E)*
2 "independent" classifiers
that can be combined to obtain an overall
"**Prompt signal classifier**"



anti-p/anti-D separation: delayed signal

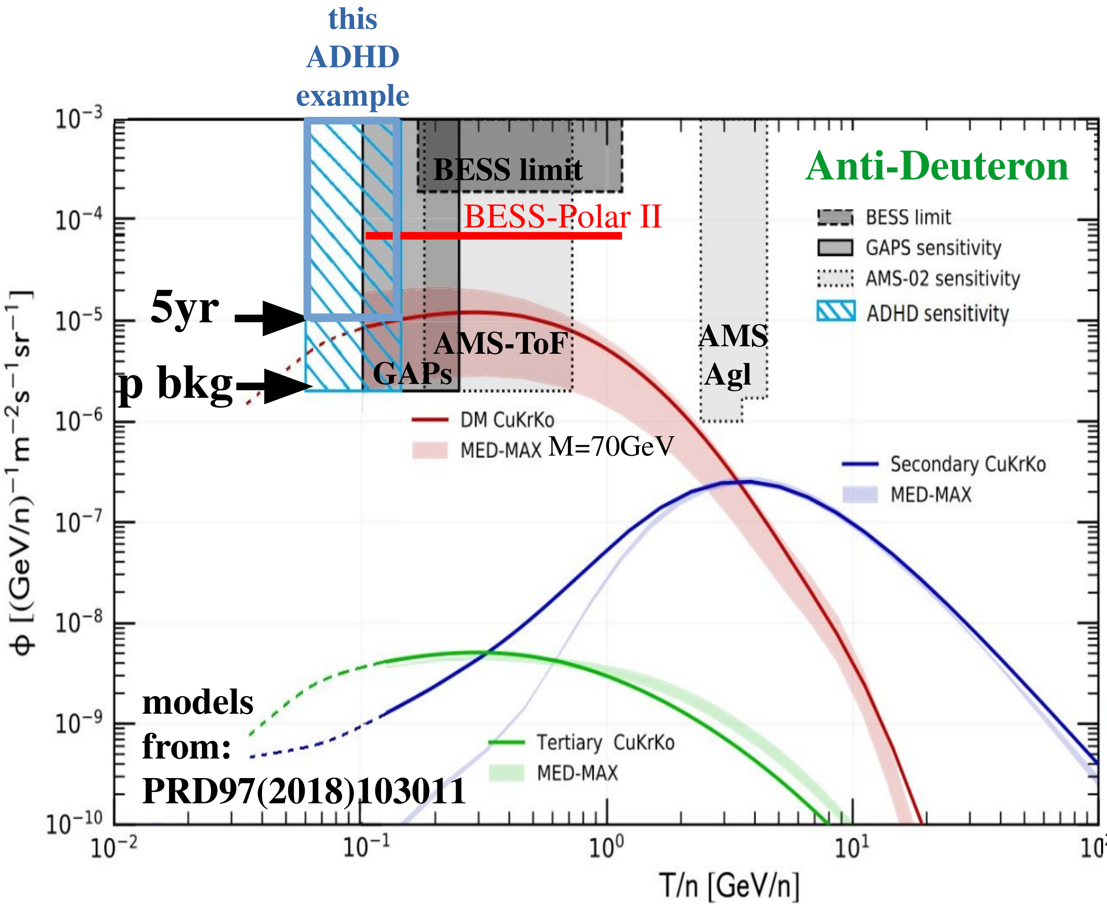
delayed signal amplitude is independent from Ekin: ~3 charged pion/antinucleon
-ToF delayed activity classifier = #ToF delayed hits ⊕ ToF delayed energy
(might improve with full track topology)

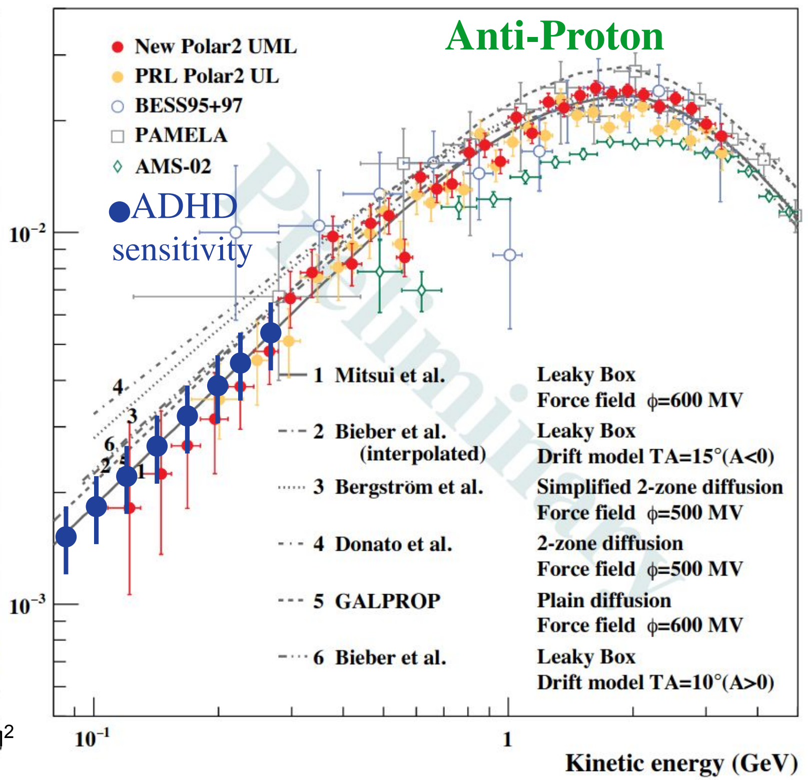




Prompt & Delayed "independent" classifiers can be combined
to obtain an overall "**signal classifier" -> possibility to detect 1anti-D/1000 anti-p**

planned sensitivity for this example (1 single ⊘ = 90cm COPV)



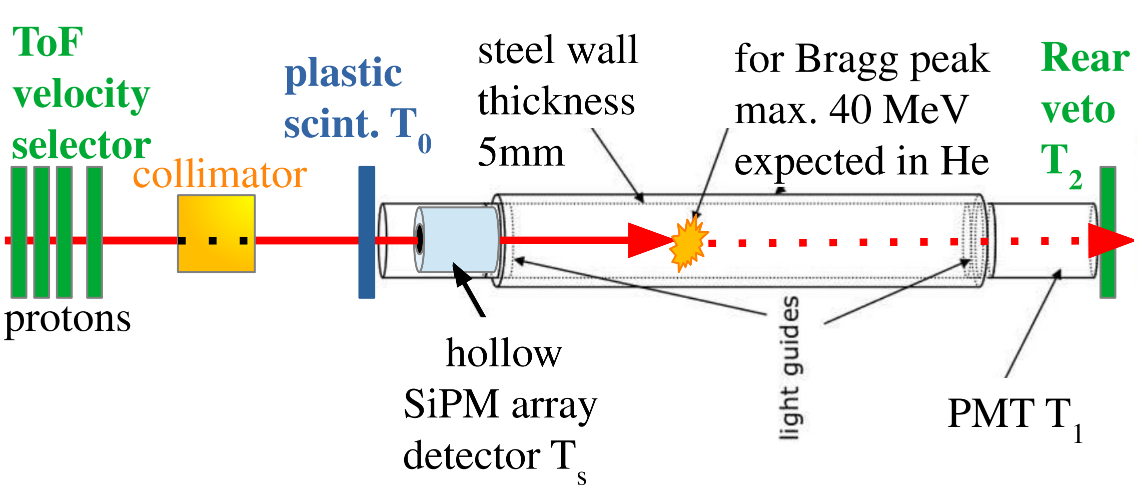


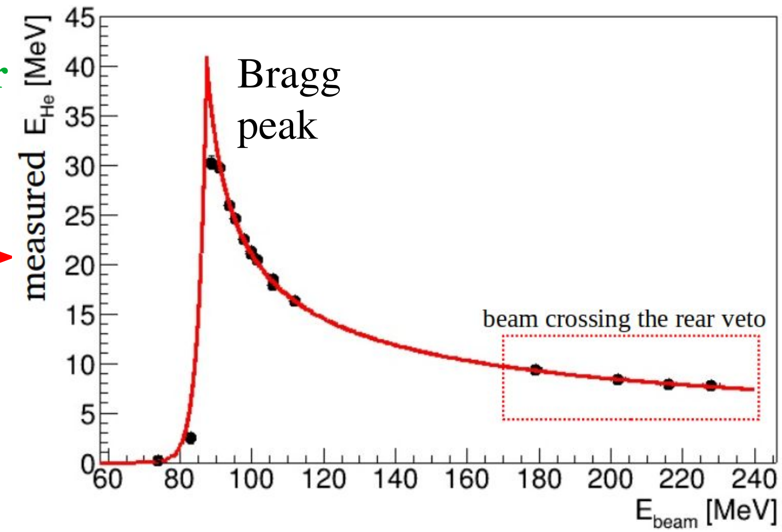
AMS02-GAPS-ADHD: different techniques, similar sensitivity, complementary Ek regions

Join many signatures in a future/ultimate Antideuteron detector?

2019-2021 “Grant-73 INFN”
Preliminary measurements on a 200bar Helium Calorimeter prototype
@ INFN-TIFPA

PROTONS (70-228MeV) @ TRENTO Proton-Therapy center

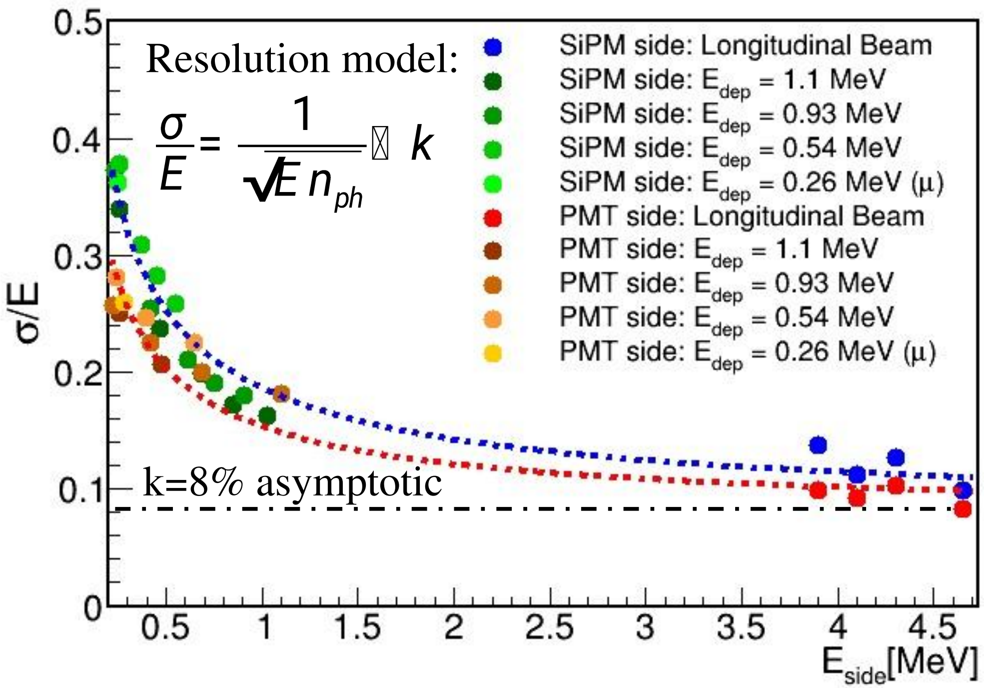


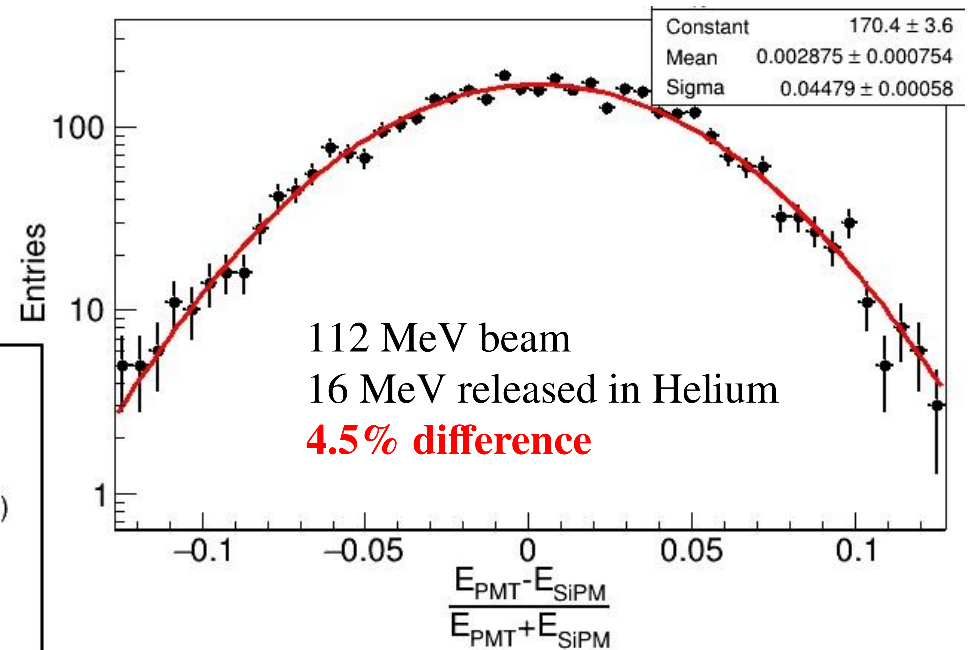


Achieved energy resolution requirements

Use of 4 proton Ek crossing the whole detector:

E_Beam	<E_He>	E_deposited in He
228MeV	190 MeV	7.7 MeV
216MeV	175 MeV	7.9 MeV
202MeV	160 MeV	8.4 MeV
179MeV	140 MeV	9.3 MeV





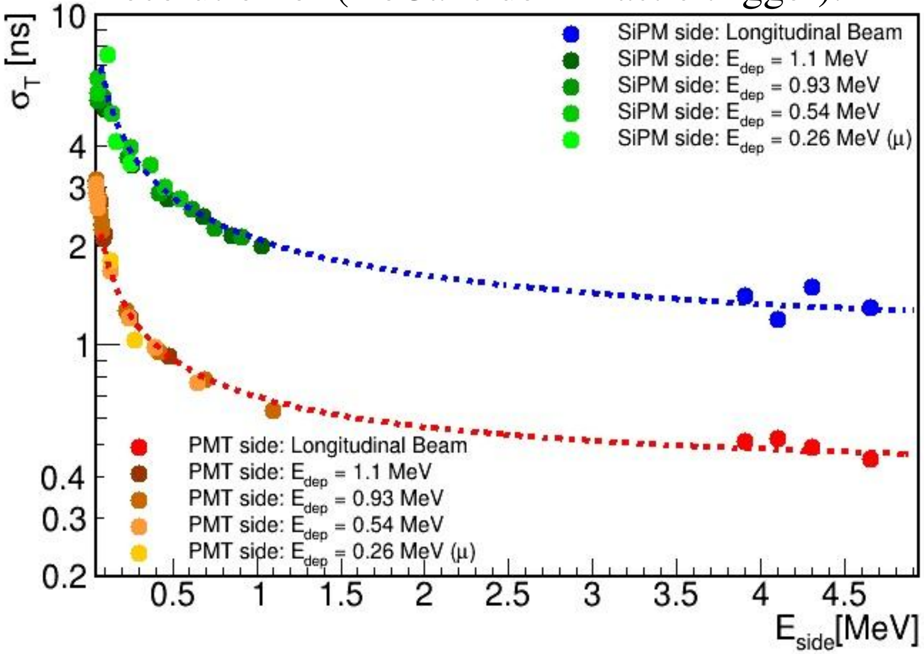
SiPM side: n_{ph} = 34.5±1.6 ph.e/MeV
PMT side: n_{ph} = 56.4±4.1 ph.e/MeV

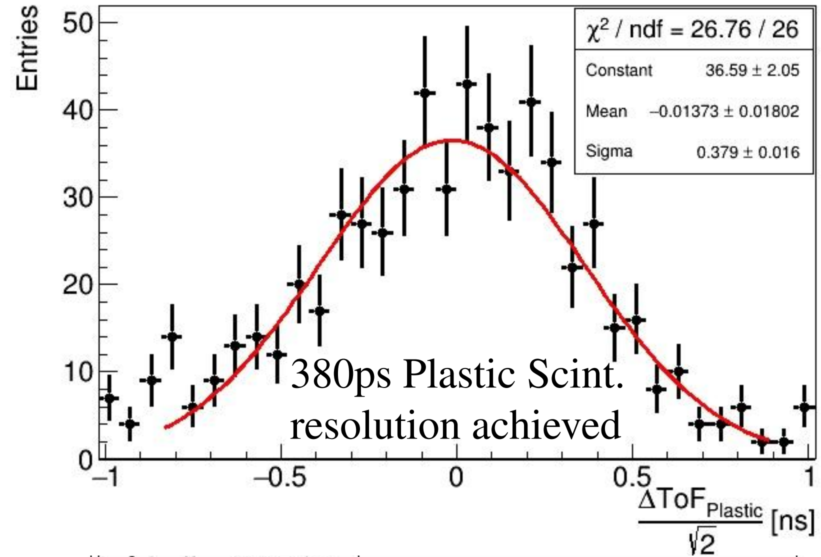
Ratio of n_{ph} PMT/SiPM = 1.63±0.14
(expected ~1.3 by surface ratio x $PMT_{QE}/SiPM_{FillFactor}$)

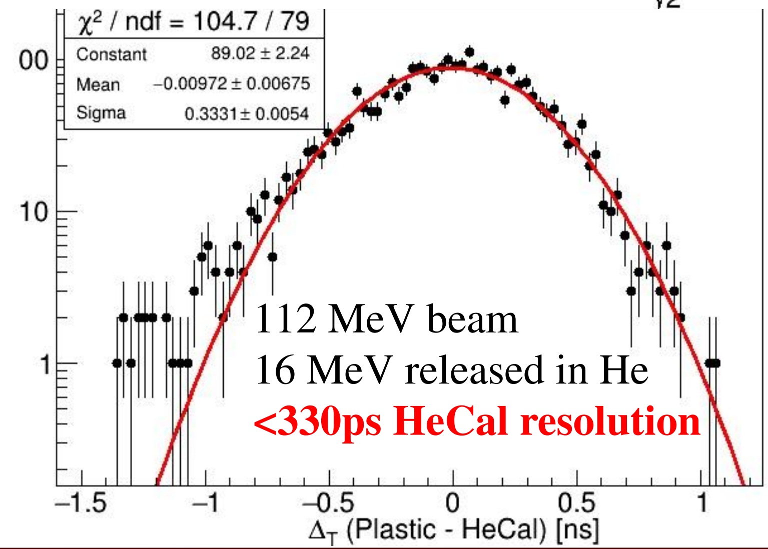
Energy resolution better than 10% achieved (ADHD goal)

Achieved time resolution requirements

Resolution of (HeCal side – Plastic trigger):

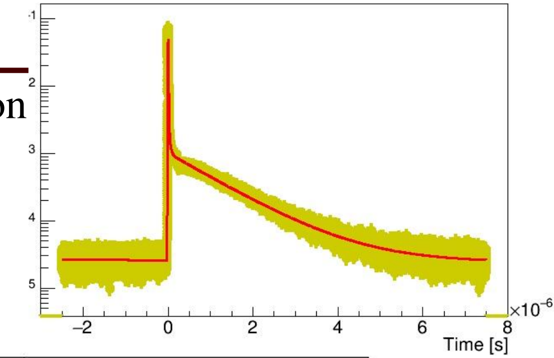




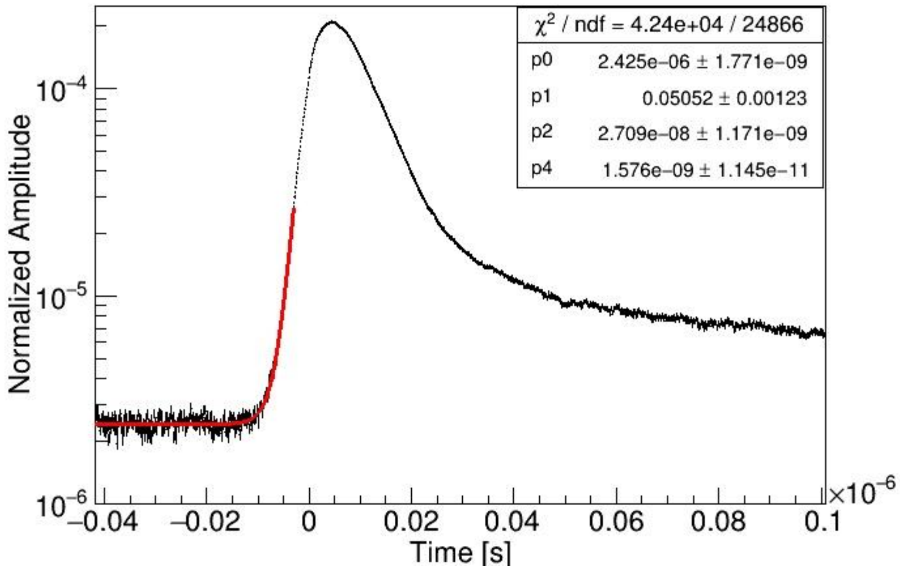


In the case of HeCal PMT side this is dominated by the time resolution of the Plastic scintillator (380 ps)
(**it is possible that ~300ps is a limit our 5Gs/s DAQ**)

Measurement of Helium Scintillation Components

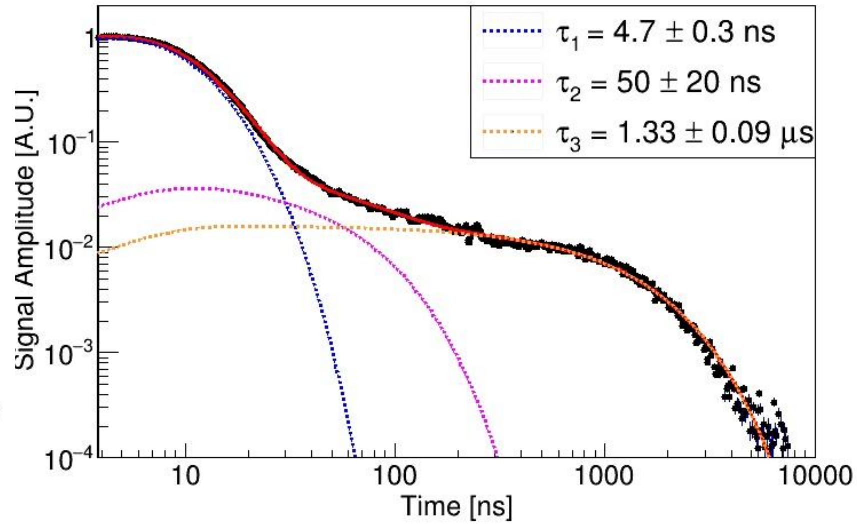


Waveform sampling @ 5Gs/s: Measurement of time structure of He scintillation
- Precise measurement of rise time and fast component decay time @ 200 bar
- First indication for a subdominant ~50ns decay component.



Fast exponential rise: τ_{grow} = 1.60±0.05ns

by comparison with the same DAQ we test a FNAL-NICADD plastic scintillator:
τ_{grow} = 0.37±0.07ns and τ_1 = 3.8±0.5ns
(and no evidence for τ_2 in this case)



3 scintillation component: $\frac{N_1}{\tau_1} e^{-\frac{t}{\tau_1}} + \frac{N_2}{\tau_2} e^{-\frac{t}{\tau_2}} + \frac{N_3}{\tau_3} e^{-\frac{t}{\tau_3}}$

Measured ratios to fast component:
N_2/N_1 = (18±0.2±7)% (N_2 new indication)
N_3/N_1 = (70±7±15)% (N_3 well known)

PREVENTIVI: 2024 - 2025 - (2026)

Finanziato dall'Unione europea
NextGenerationEU

Ministero dell'Università e della Ricerca

Segretariato Generale

Direzione Generale della Ricerca

PRIN: PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE – Bando 2022
Prot. 2022LLCPMH

Project accepted: Pressurized Helium Scintillating Calorimeter for AntiMatter Identification

Requirements for INFN-TIFPA

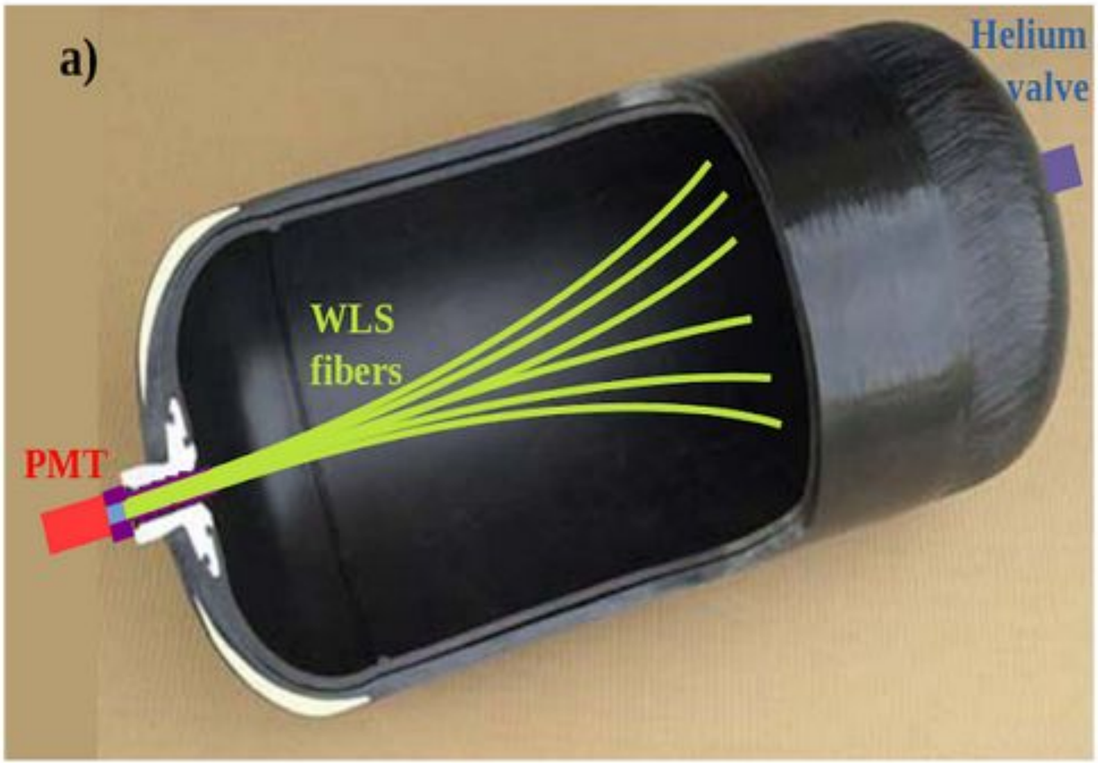
- **4mesi/anno da rendicontare sul progetto per Spinnato, Rashevskaya, Verroi**
- **laboratory space + Proton beam time**
- **technical support (Mechanics & Electronics) sempre più urgente un tecnico TIFPA**
- **amministation support (ordini per 93keuro da spendere in 2 anni)**

Requirements for UniTN (additional 93keuro resp. prof. P. Zuccon)

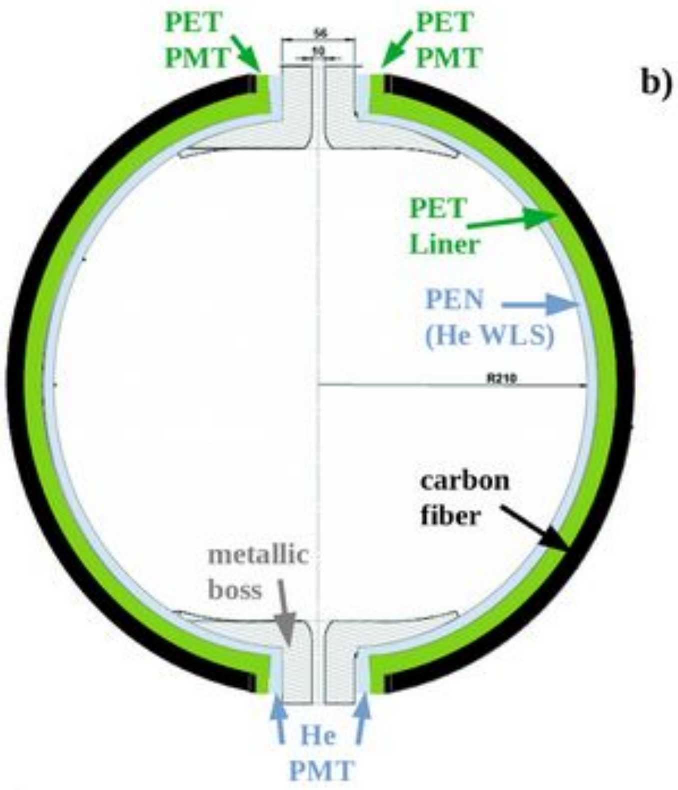
- **supervisor of PhD scholarship starting from Nov. 2023 (Short deadline HELP!)**

expected outcomes: 2024 - 2025

Development and test of HeCal prototype Based on commercial (automotive) COPV

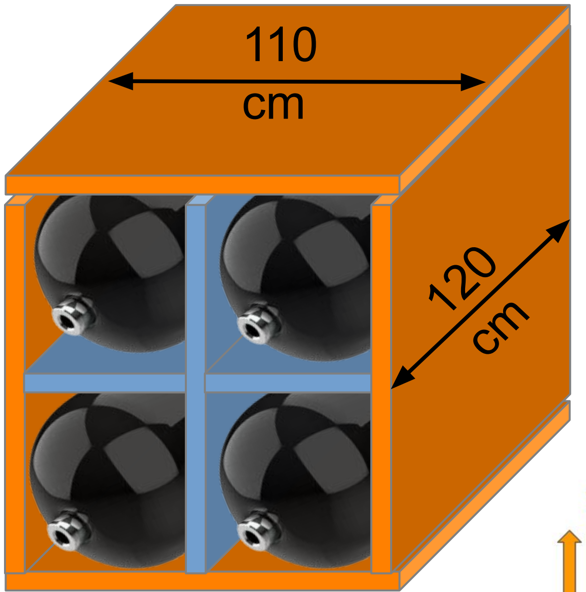


Development and test of a COPV including a "fast" scintillating layer in the vessel



PET and PEN are stronger than Copper and fast scintillating (6.8ns and 35 ns) (https://doi.org/10.3906/fiz-1912-9)

2026: ADHD demonstrator for a balloon launch
2x2x2 ⊘ = 50cm He modules



https://www.tifpa.infn.it/projects/adhd/

… pathfinder for the "ADHD-Science" circumanctartic balloon (3m x 3m x 3m)