# Anti Deuteron Helium Detector


2nd Cosmic-ray Antideuteron Workshop UCLA

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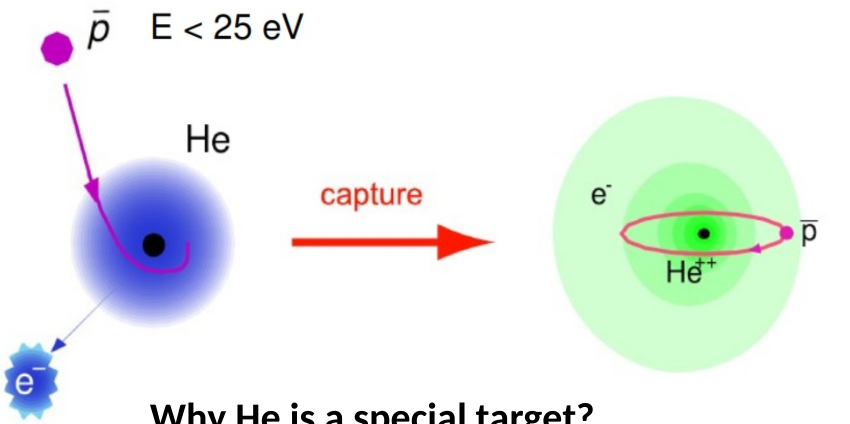
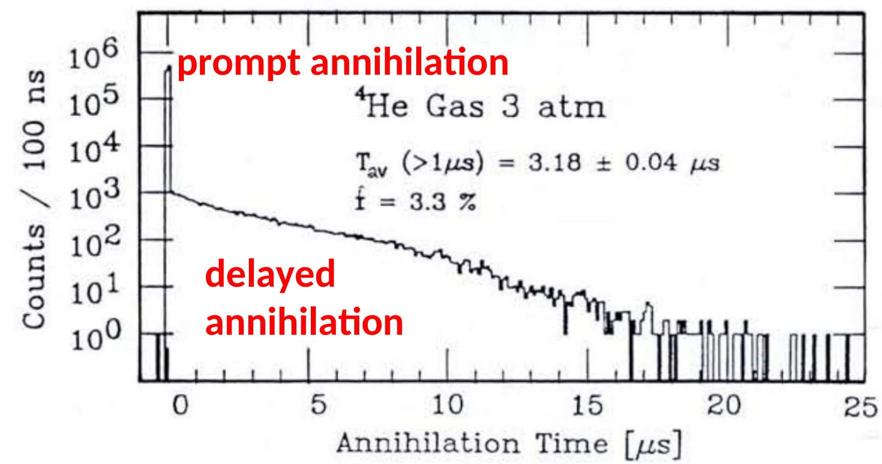
# a possible "new" signature: He metastable states




-In matter lifetime of stopped $\bar{p}$ is ~ps
-In liquid/gas He delayed annihilation: few μs (~3% of the $\bar{p}$)(discovered @ KEK in 1991)
The electron is on 1s ground state, while the $\bar{p}$ (or also $\pi^-$,$k^-$,$\bar{d}$) occupies a **large n** level (~38 for $\bar{p}$) (~same bounding energy of the ejected e- )
**Theory: Phys. Lett. 9 (1964) 65 PRL 23 (1969) 63**

**Why He is a special target?**

1) 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 $\bar{p}$
=> metastability is unexpected and excluded for Z>3 atoms (metastability for $Li^+$ target? → still not confirmed by expt.)




2) the remaining electron in $\bar{p}$He suppresses the collisional Stark effect (the main de-excitation channel for $p\bar{p}$ system)

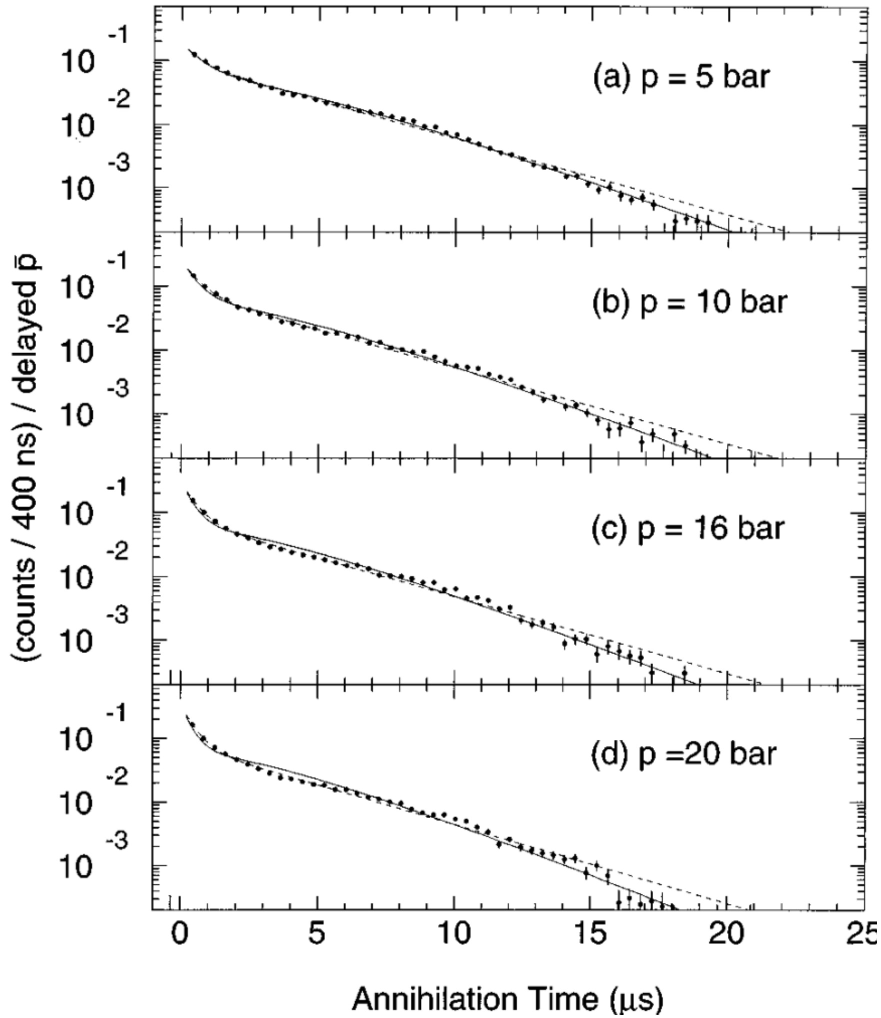
$$(p\,\bar{p})_{nl} + H \Rightarrow (p\,\bar{p})_{nl'} + H$$

**a signature for Z=-1 antimatter capture in He is a ~μs delayed energy release (in ~3% of cases)**

**Not really new: similar effect already proven, and used, by the ASACUSA experiment**

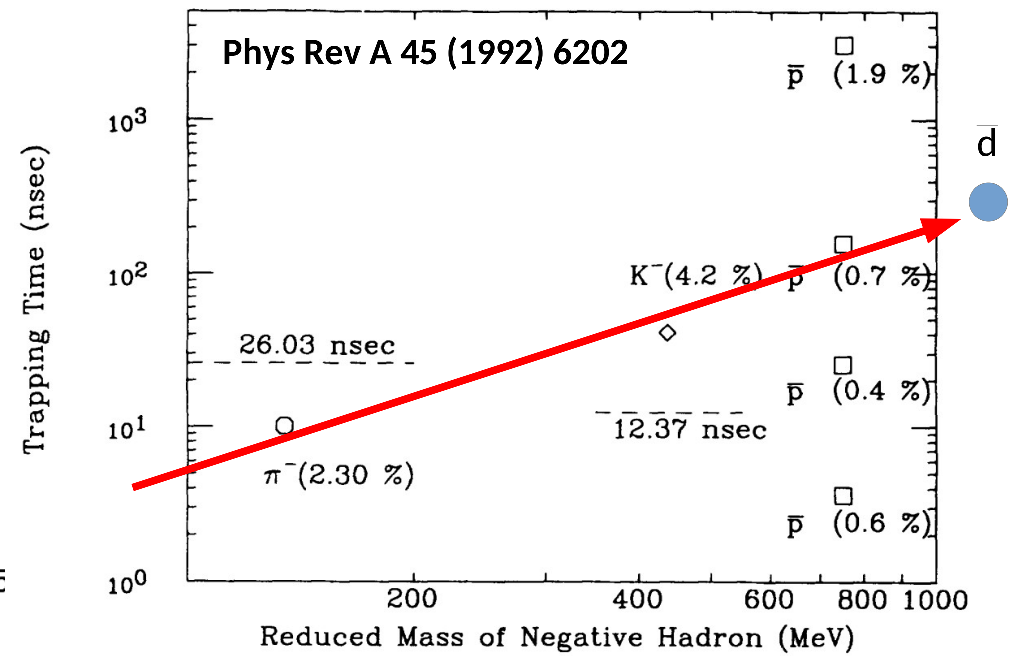
# Lifetime & fraction vs pressure vs particle mass

**Phys Rev A 53 (1996) 3129** He @ room Temperature



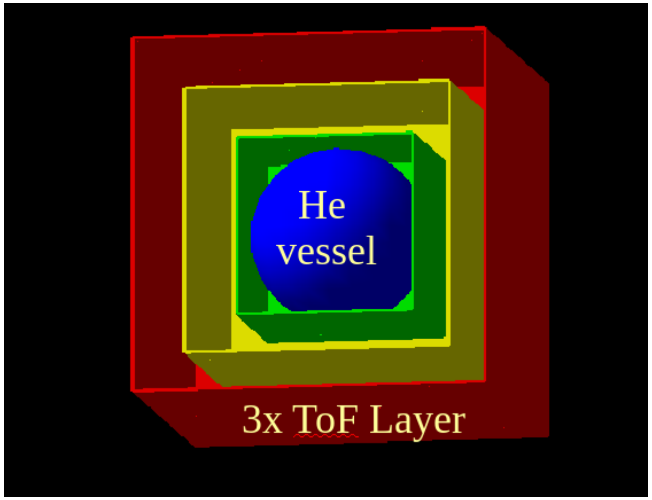

NOT a pure exponential:
Fast and Slow components
**Increasing Pressure → Fast component increase**

Isotope effect:
expected lifetime increase as squared of the reduced mass => **expected for antideuterium**

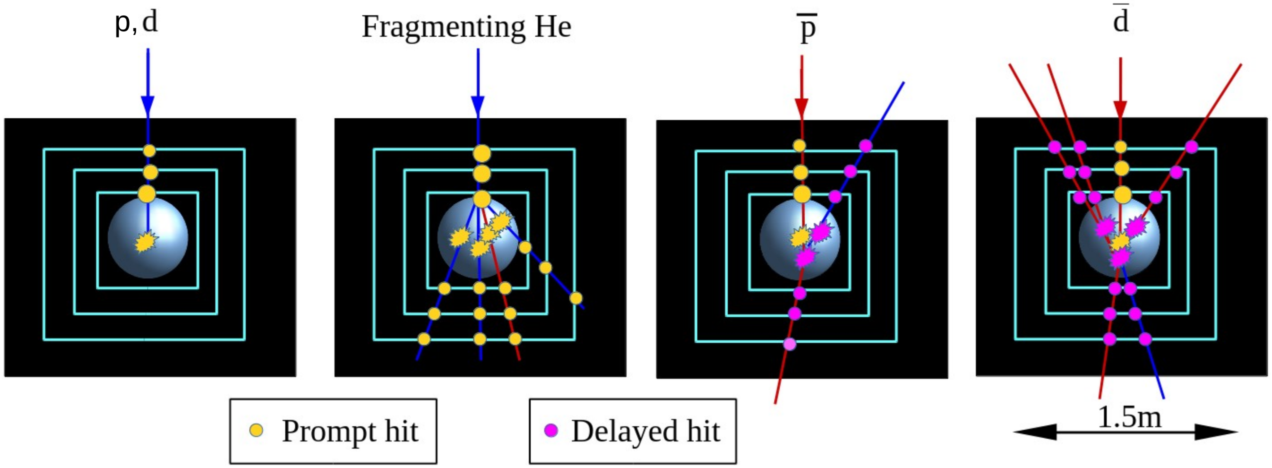


# Anti Deuteron He Detector (ADHD)

**Concept**: HeCalorimeter (scintillator)
3xTime of Flight (compact) layers



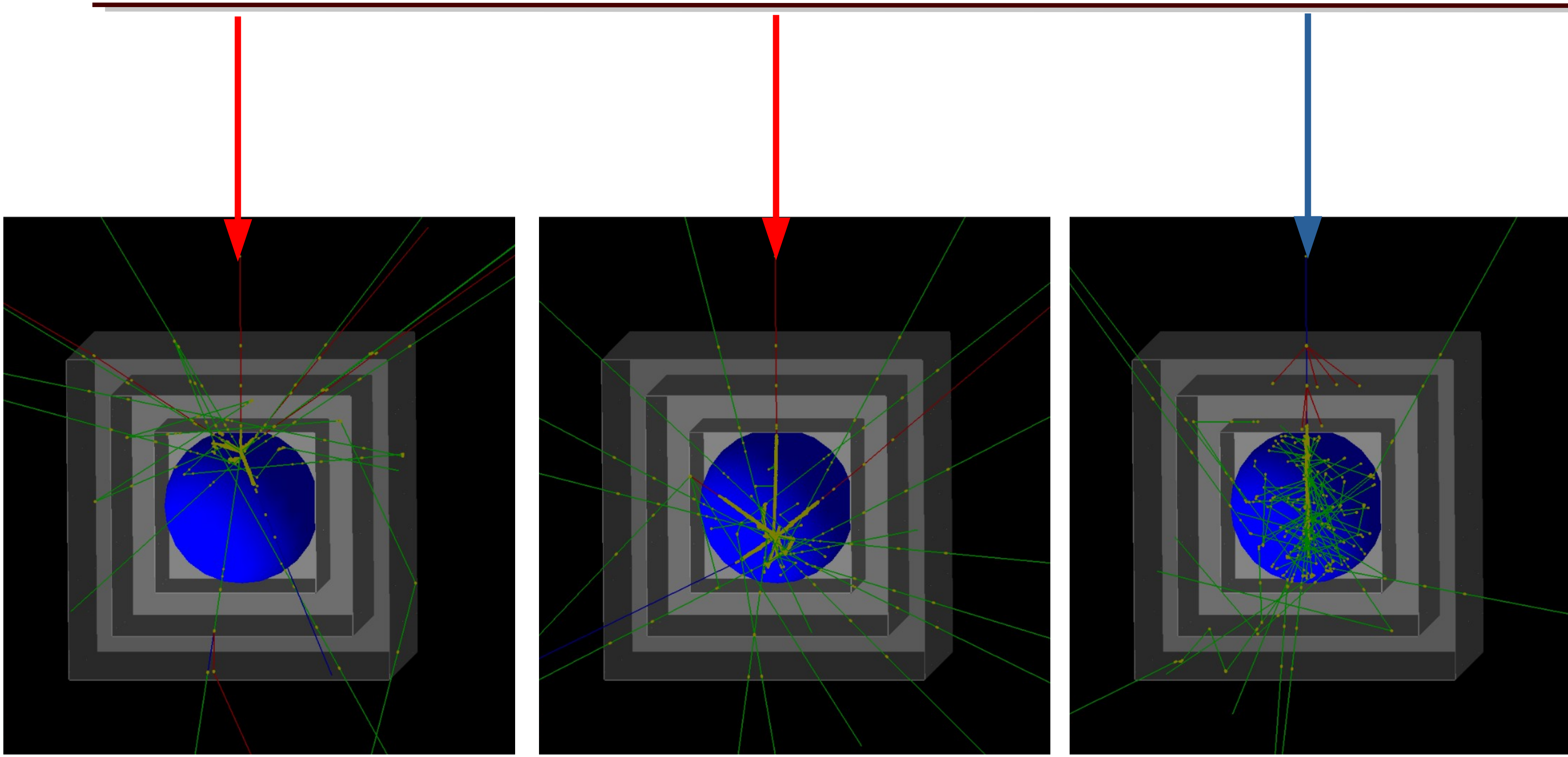

Status: preliminary Geant4 simulation
Detector size: External ToF L = 1.5m;
Vessel R=45cm Thick=3cm "thermoplastic"
He pressure 400bar (typ. He bottle 130bar)
("commercially" feasible space qualified)
Detector mass: He = 20 kg Vessel = 100kg
ToF = 110 kg ( 4mm scintillator thickness)
Kinetic energy range: 0.06-0.15 GeV/n
(threshold due to energy loss in vessel/ToF)




Particle identification by:
1) timing of tracks
2) dE/dx on ToF
3) Beta ToF
4) Prompt HeCal Energy
5) Delayed HeCal Energy
6) event topology

## GEANT4

**$\bar{d}$ (65MeV/n)** **$\bar{p}$ (230MeV)** **Carbon (600MeV/n)**

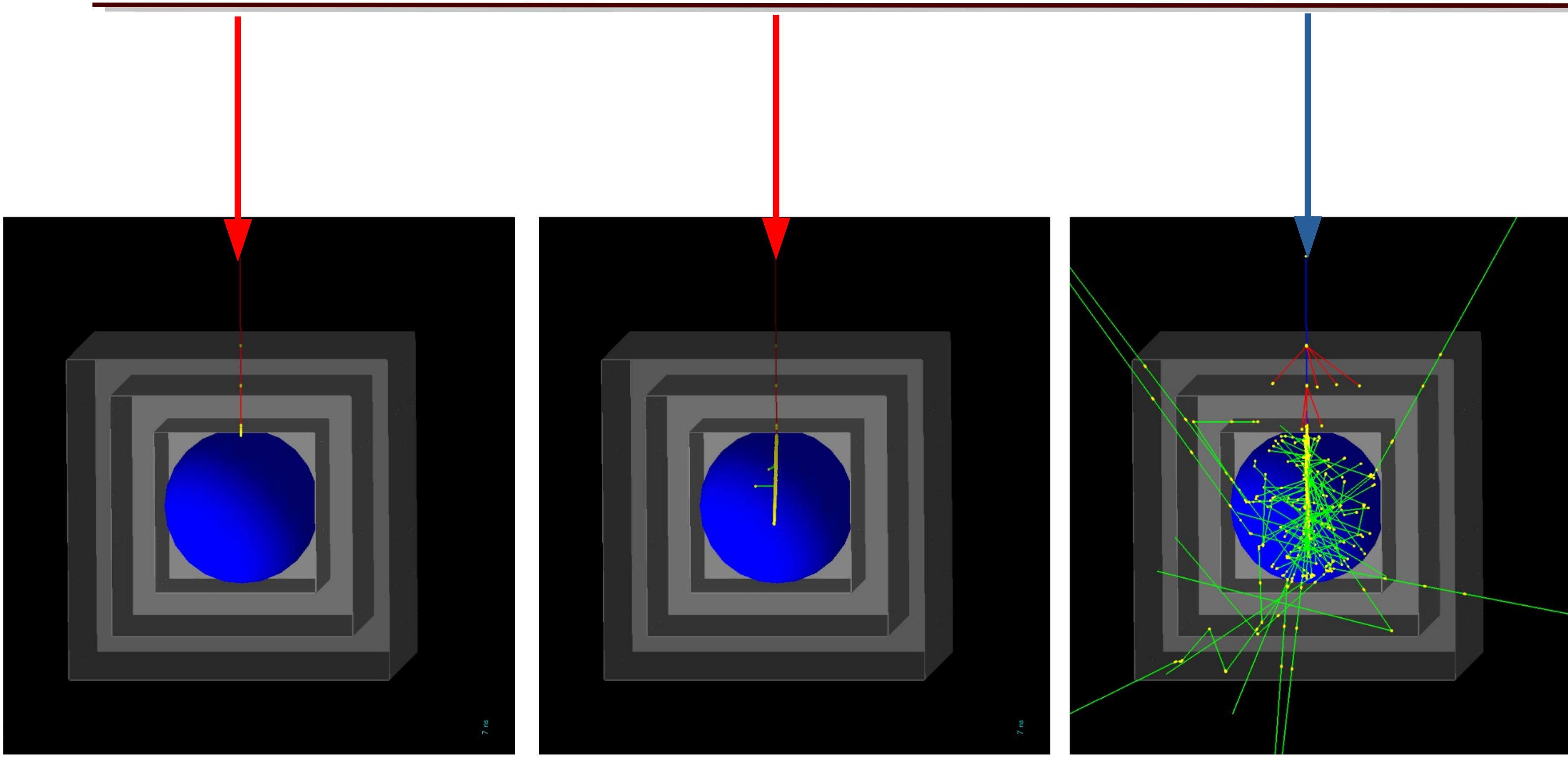


4 charged outgoing (+ pair production) | 3 charged outgoing | 0 charged outgoing

**Negative** **Positive** **Neutral** charges

## [0-7] ns

**$\bar{d}$ (65MeV/n)** **$\bar{p}$ (230MeV)** **Carbon (600MeV/n)**



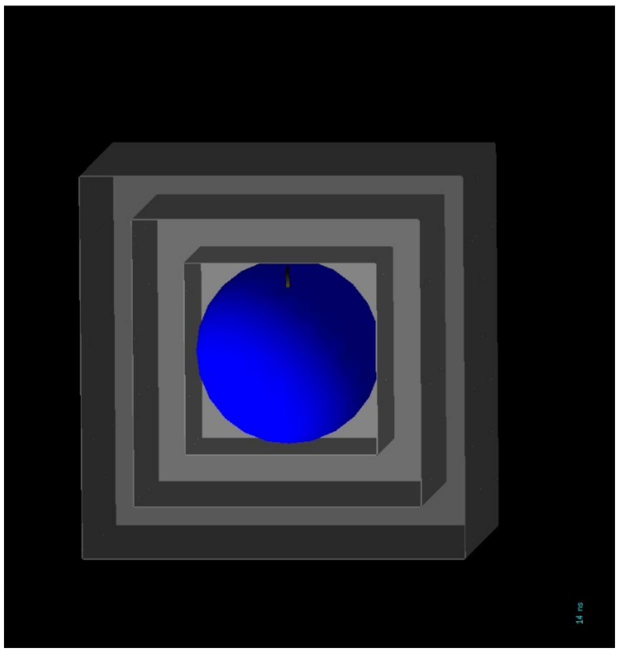
… ok it is slow …
prompt HeCal signal
3 hits in ToF

prompt HeCal signal
3 hits in ToF

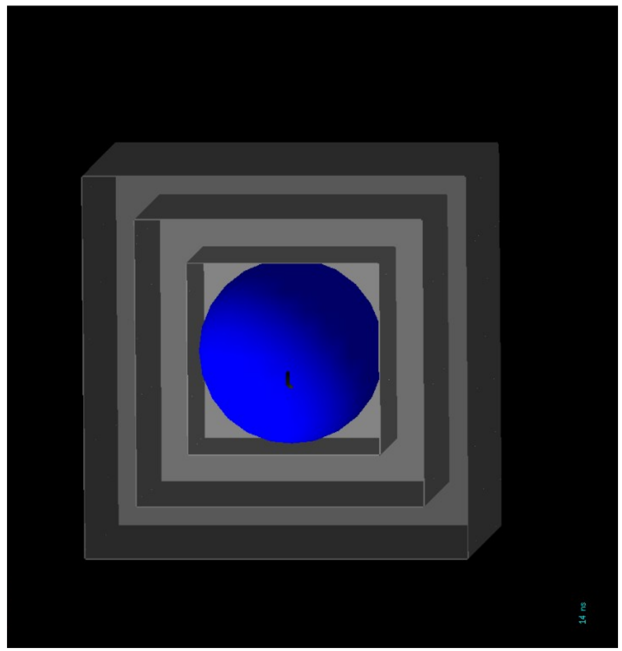
prompt HeCal signal
10 hits in ToF

## [7-14] ns

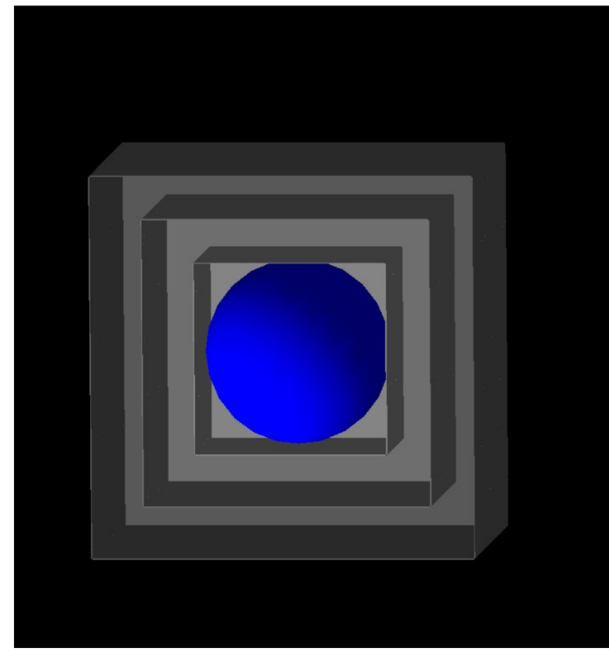
**$\bar{d}$ (65MeV/n)** | **$\bar{p}$ (230MeV)** | **Carbon (600MeV/n)**



stopped by HeCal
small tail in prompt
HeCal signal



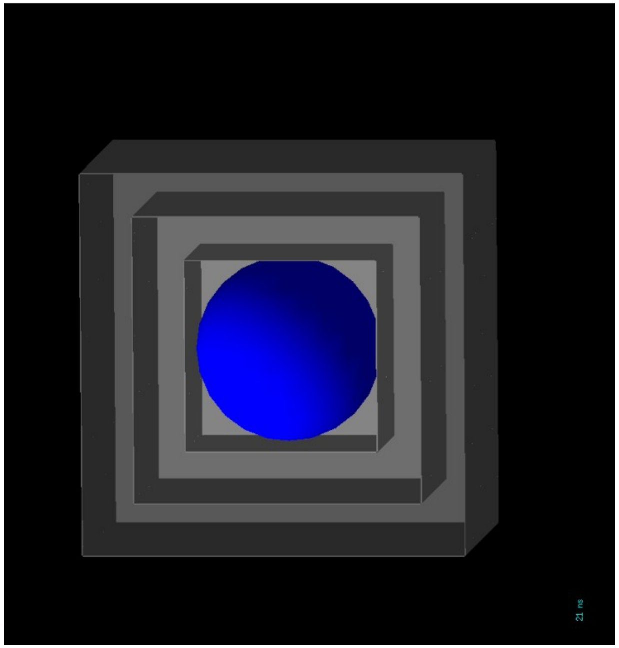
stopped by HeCal
small tail in prompt
HeCal signal



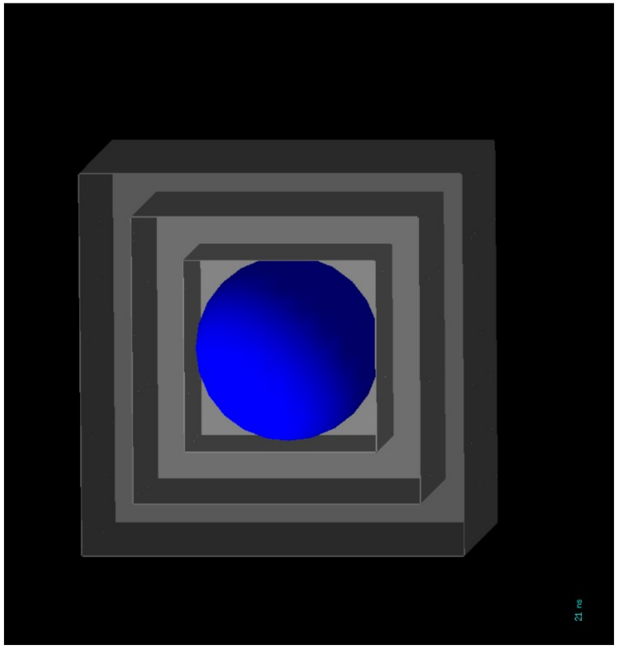
...nothing

# [14-60] ns

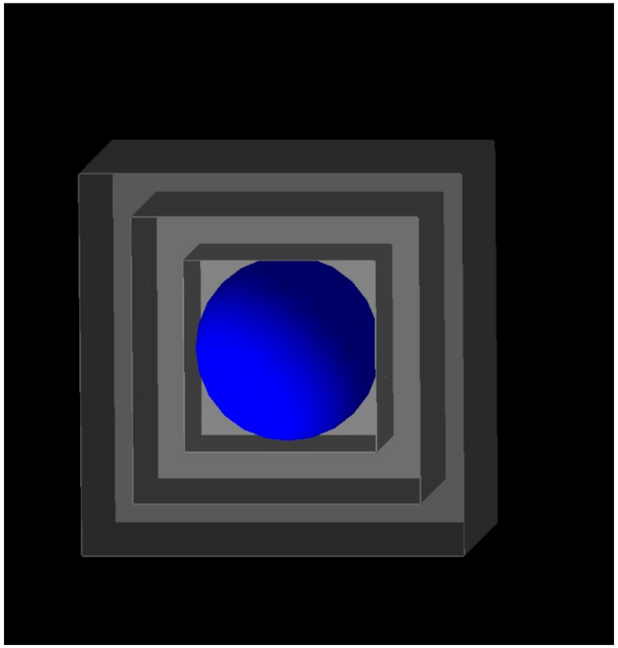
**$\bar{d}$ (65MeV/n)** | **$\bar{p}$ (230MeV)** | **Carbon (600MeV/n)**



Antideuteron orbiting He



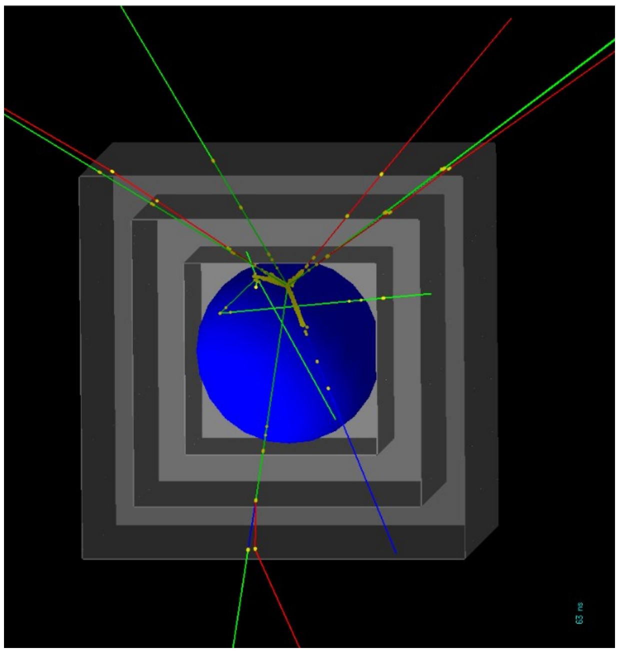
Antiproton orbiting He



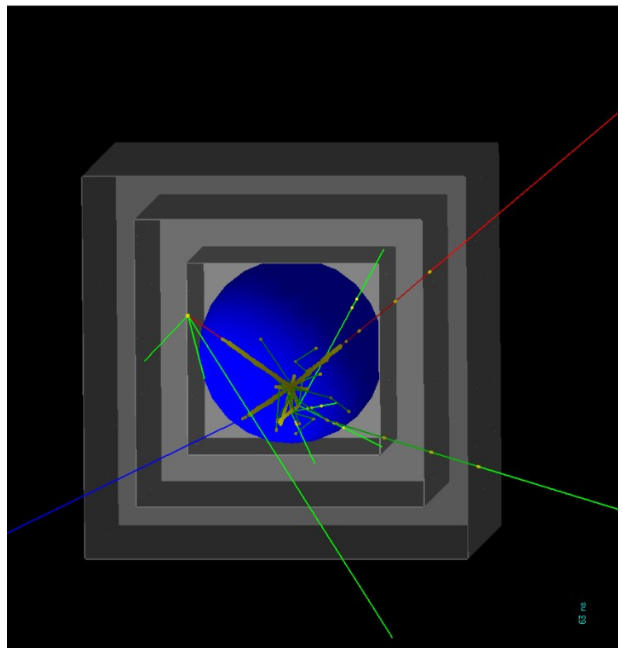
...nothing

# [60-70] ns

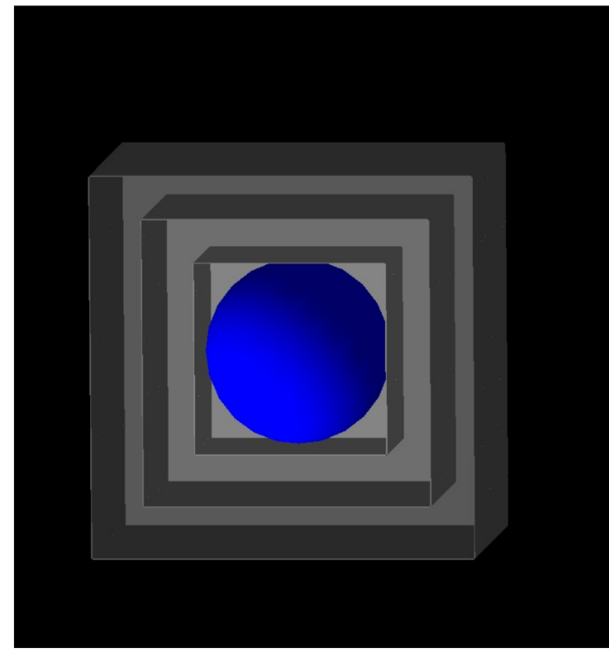
**$\bar{d}$ (65MeV/n)** **$\bar{p}$ (230MeV)** **Carbon (600MeV/n)**



Antideuteron annihilation



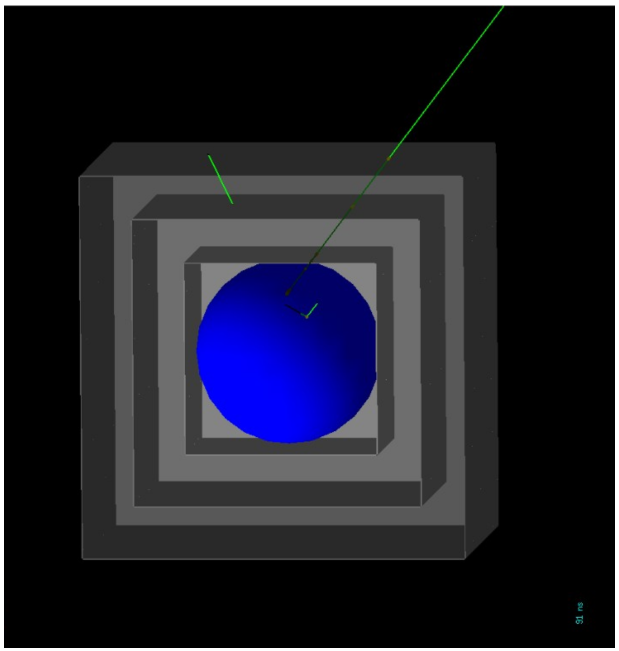
Antiproton annihilation



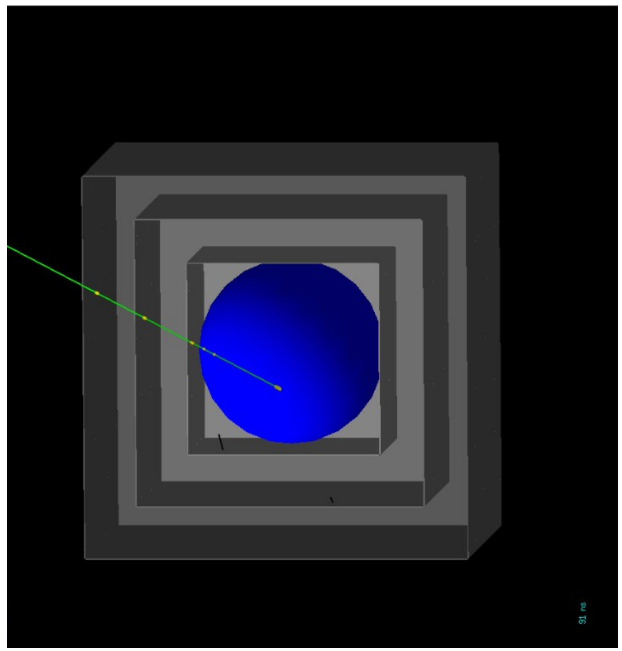
...nothing

# [70-XXX] ns

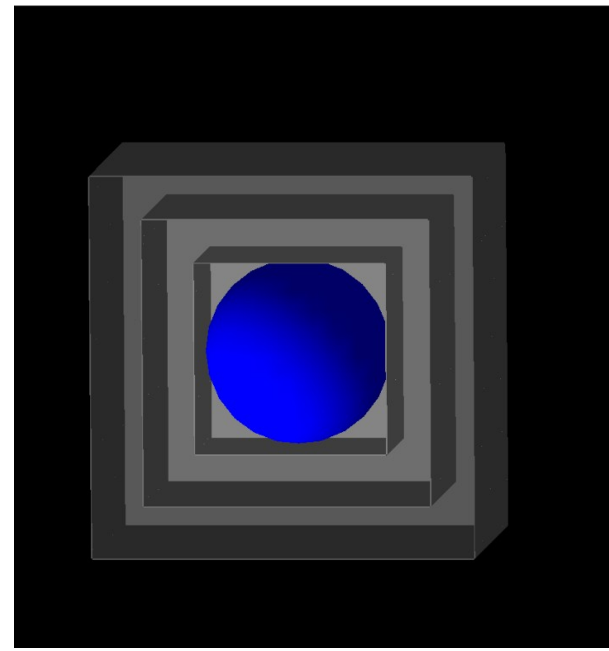
**$\bar{d}$ (65MeV/n)** | **$\bar{p}$ (230MeV)** | **Carbon (600MeV/n)**



small nuclear processes

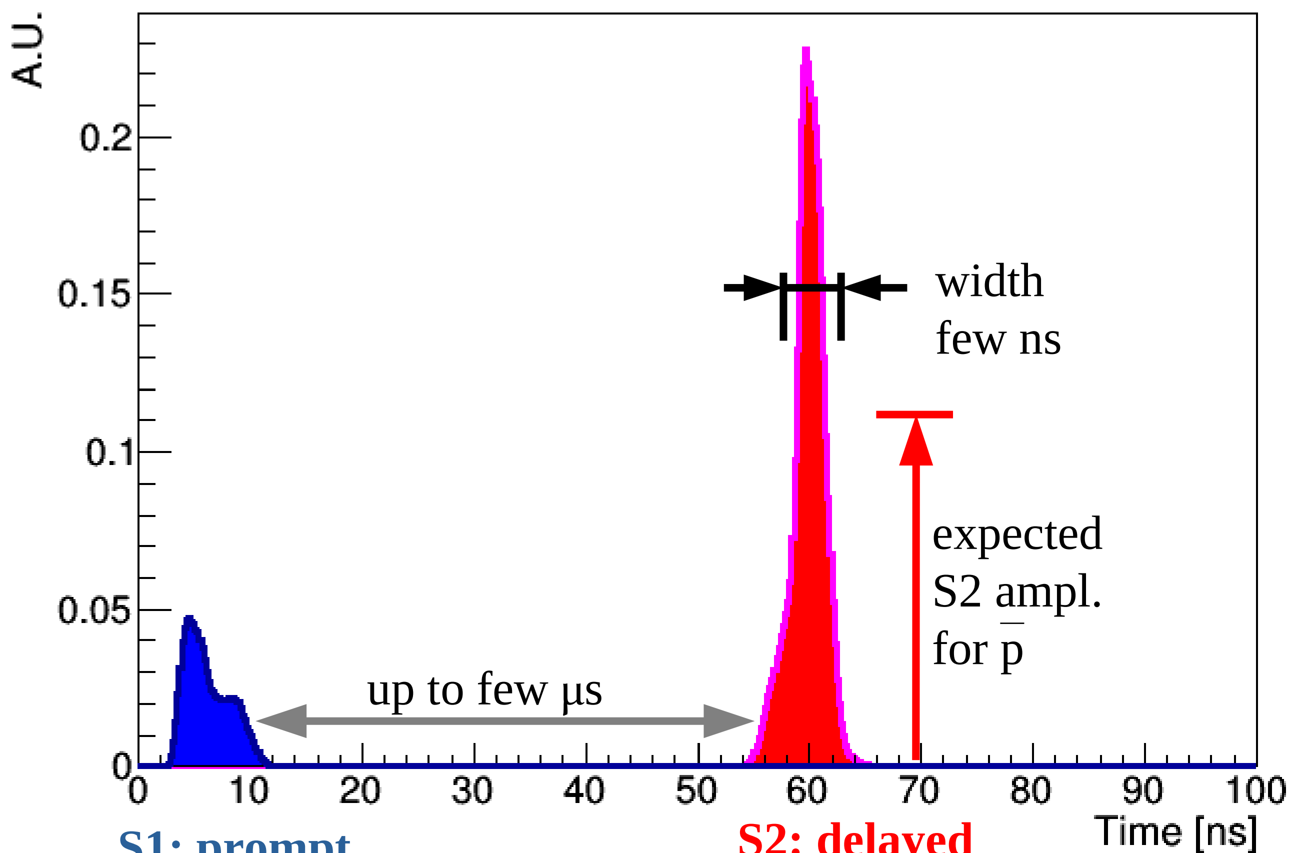


small nuclear processes



...nothing

# Typical HeCal signature for $\bar{p}$ and $\bar{d}$




**S1: prompt**

$\bar{p}$ or $\bar{d}$

kinetic energy

(- energy loss)

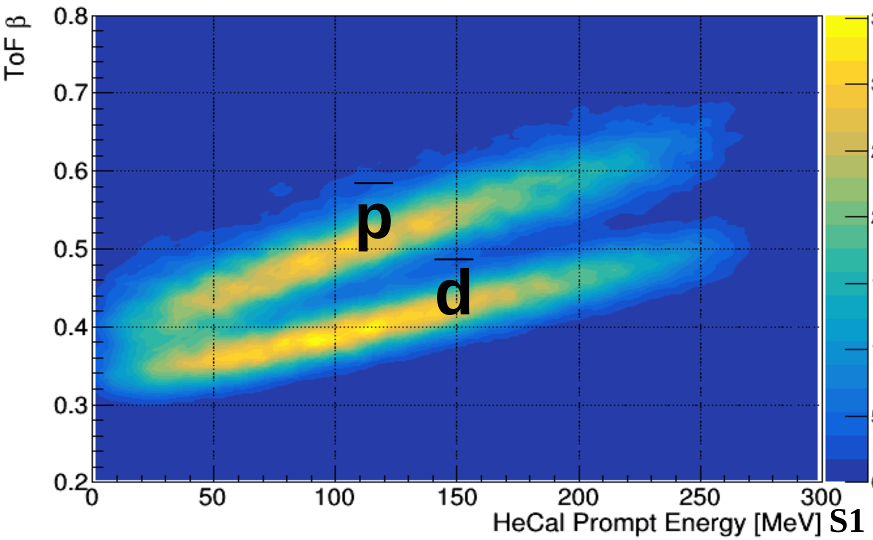
**S2: delayed**

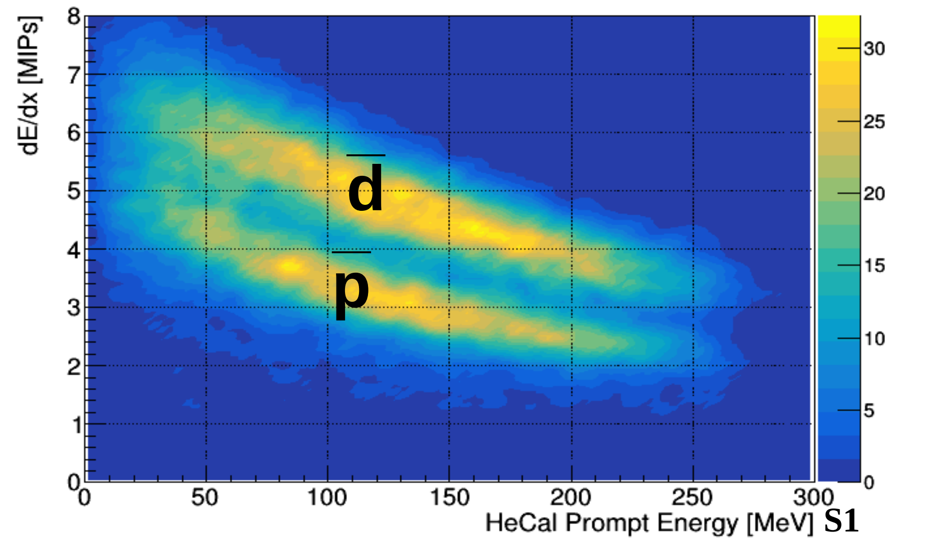
Charged π/μ

Typ. S2 > S1

S2 independent by Ek

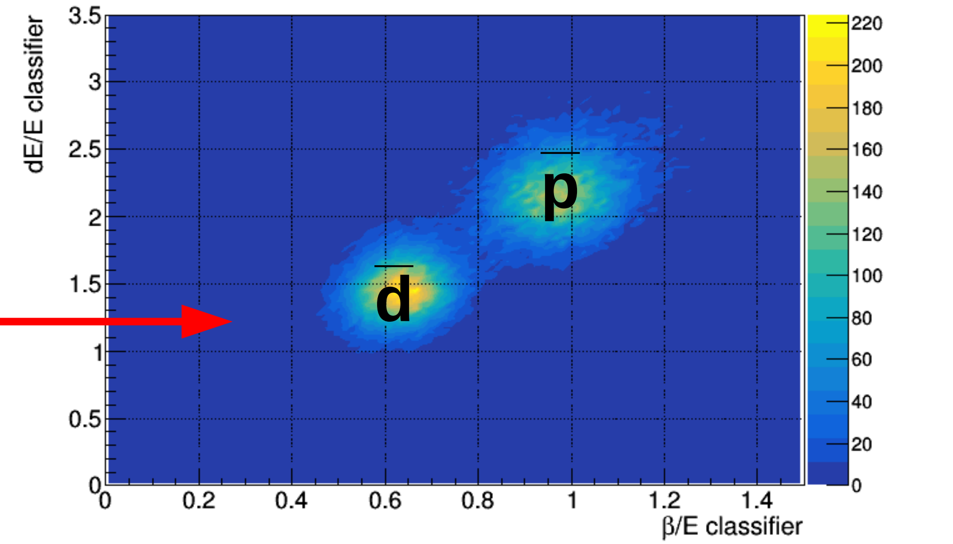
# $\bar{p}/\bar{d}$ separation: prompt signal



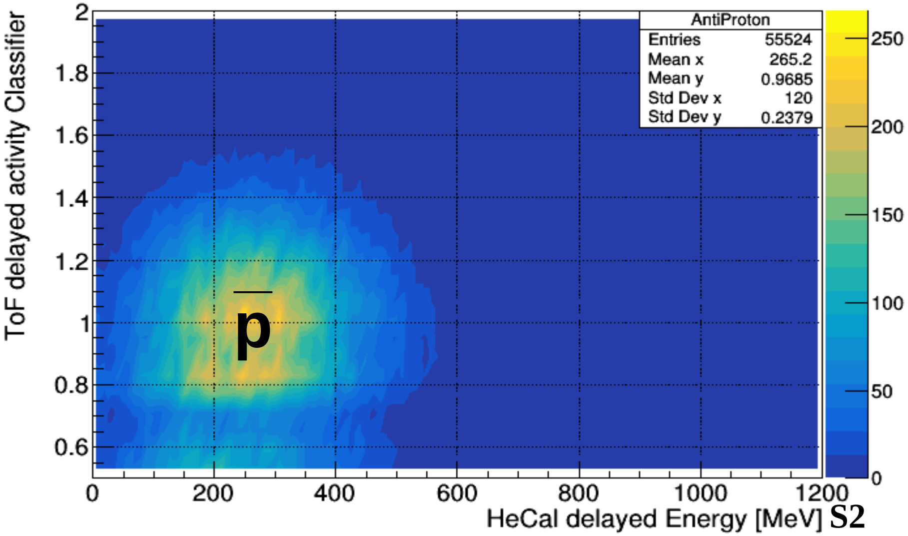

ToF goals (30cm baseline & 4mm thickness):
$\beta$ resolution 5% => $\sigma_{x/y}$ ~few cm & $\sigma_T$<0.1ns
Energy resolution 10%

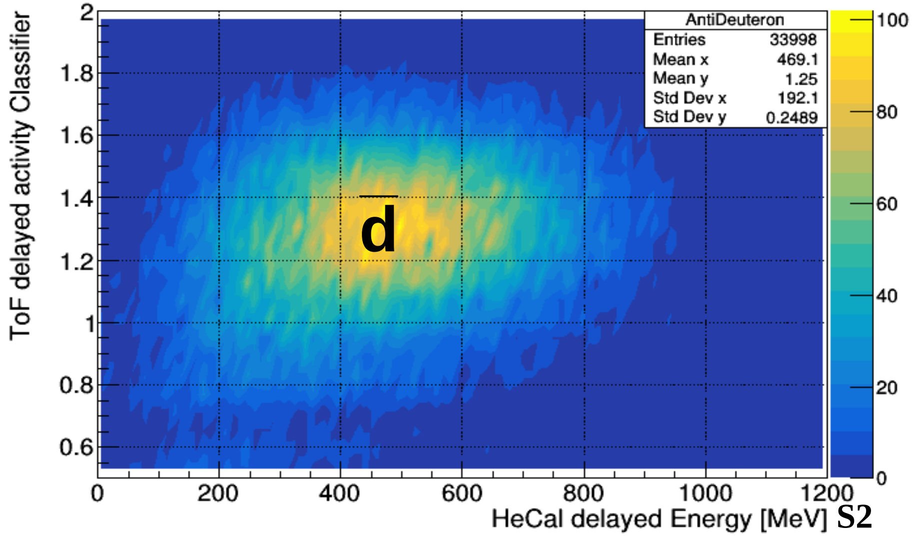
Parametrization of ( $\beta$ vs *E)* & *(dE/dx vs E)*
2 “independent” classifiers
that can be combined to obtain an overall
“Prompt signal classifier”



# $\overline{p}/\overline{d}$ separation: delayed signal

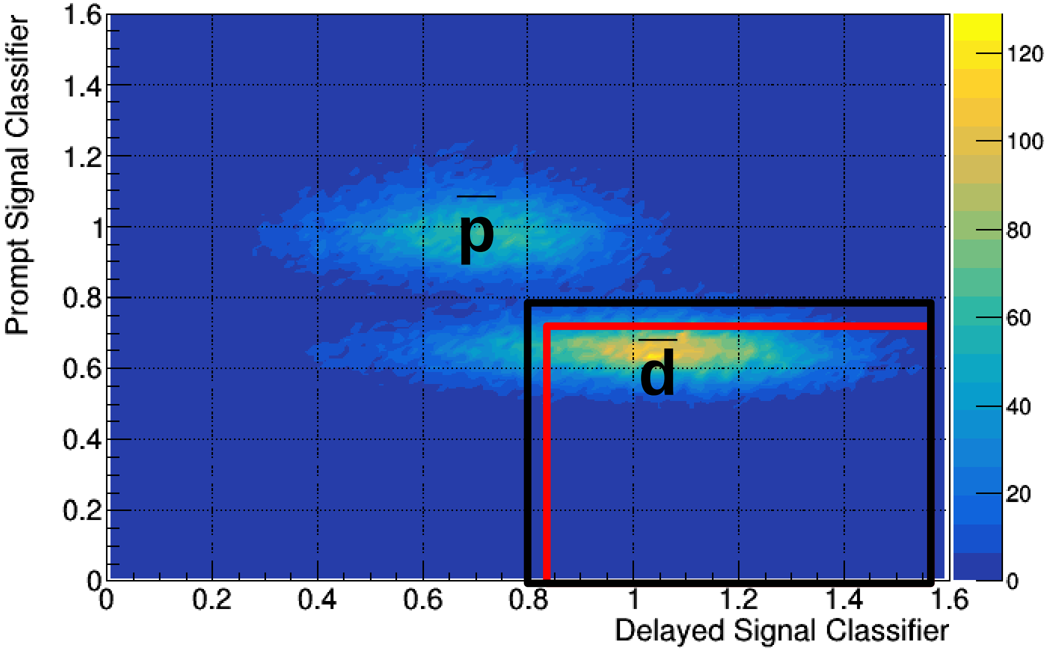
delayed signal amplitude is independent from Ekin: ~3 charged pion/antinucleon
-ToF delayed activity classifier = #ToF delayed hits $\oplus$ ToF delayed energy
(can be improved a bit with full track topology)

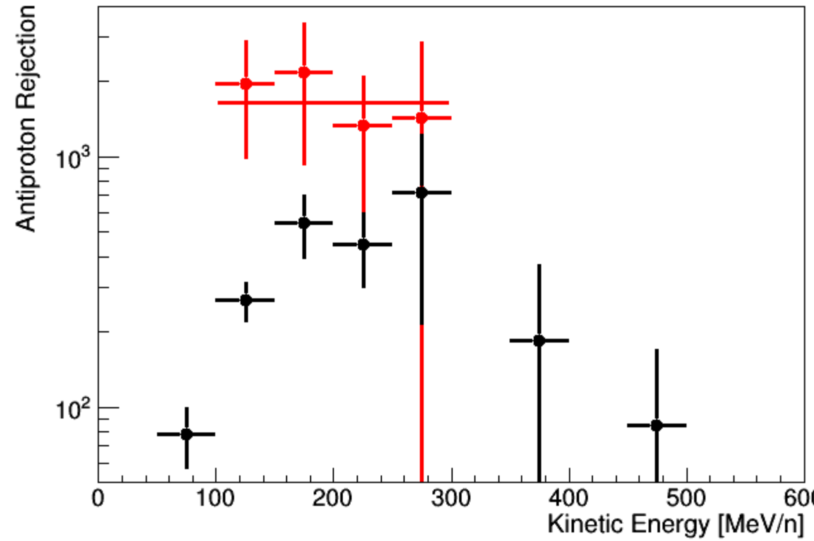


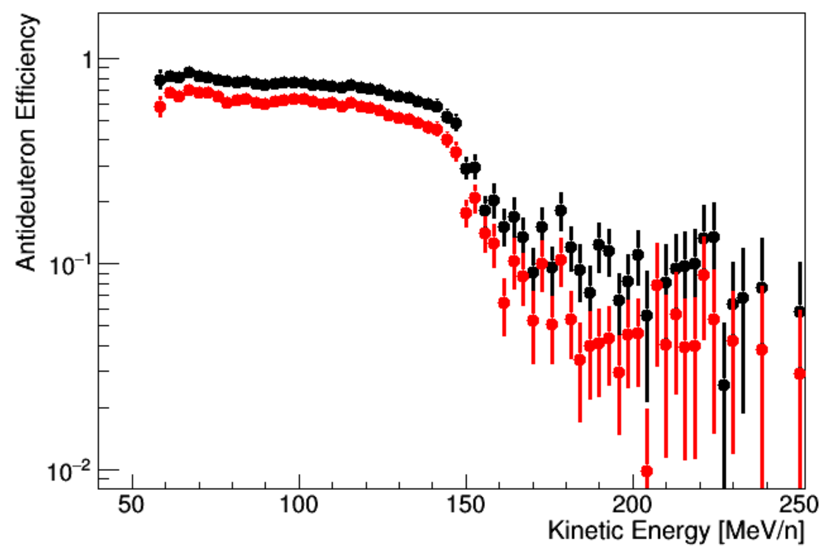




2 “independent” classifiers
that can be combined to obtain an overall
“Delayed signal classifier”

# $\bar{p}/\bar{d}$ separation



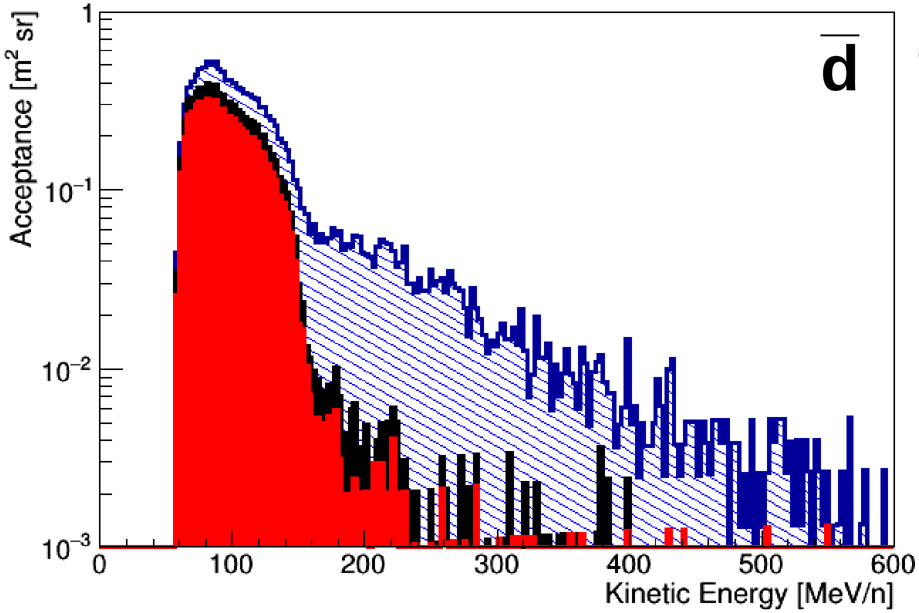



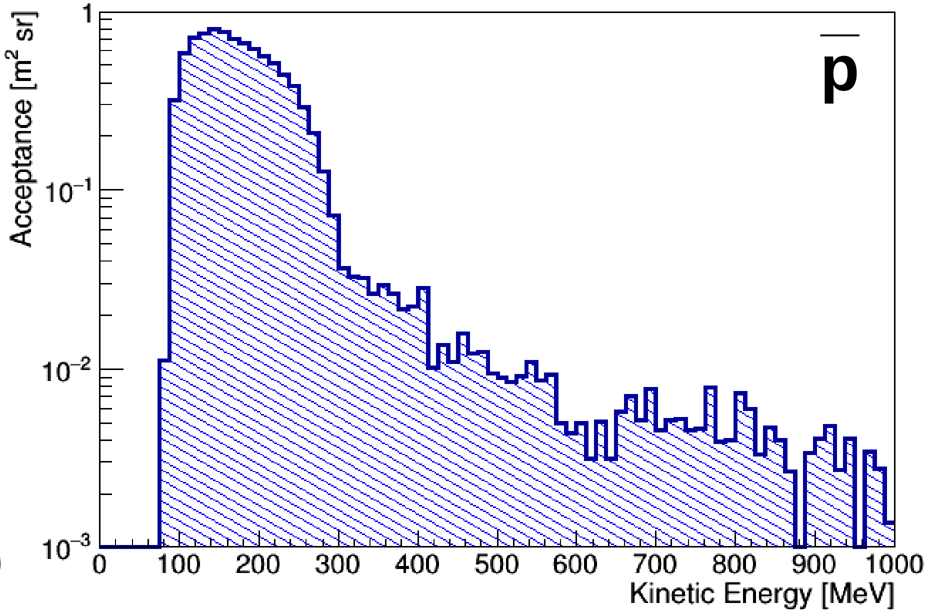




$\bar{p}$ rejection 1500 @ 65% $\bar{d}$ efficiency
=>possibility to detect 1$\bar{d}$/1000 $\bar{p}$
[50-150] MeV $\bar{p}$ flux < 2-3 x $10^{-3}$ $(m^2 s\ sr\ GeV)^{-1}$
Therefore with these ADHD performances
the $\bar{p}$ background is limiting the sensitivity to:
$\bar{d}$ flux > 2-3 x $10^{-6}$ $(m^2 s\ sr\ GeV/n)^{-1}$

# $\overline{p}/\overline{d}$ acceptances

Baseline: S1 & S2 & (dE/dx>MIP) & 3 prompt ToF hits



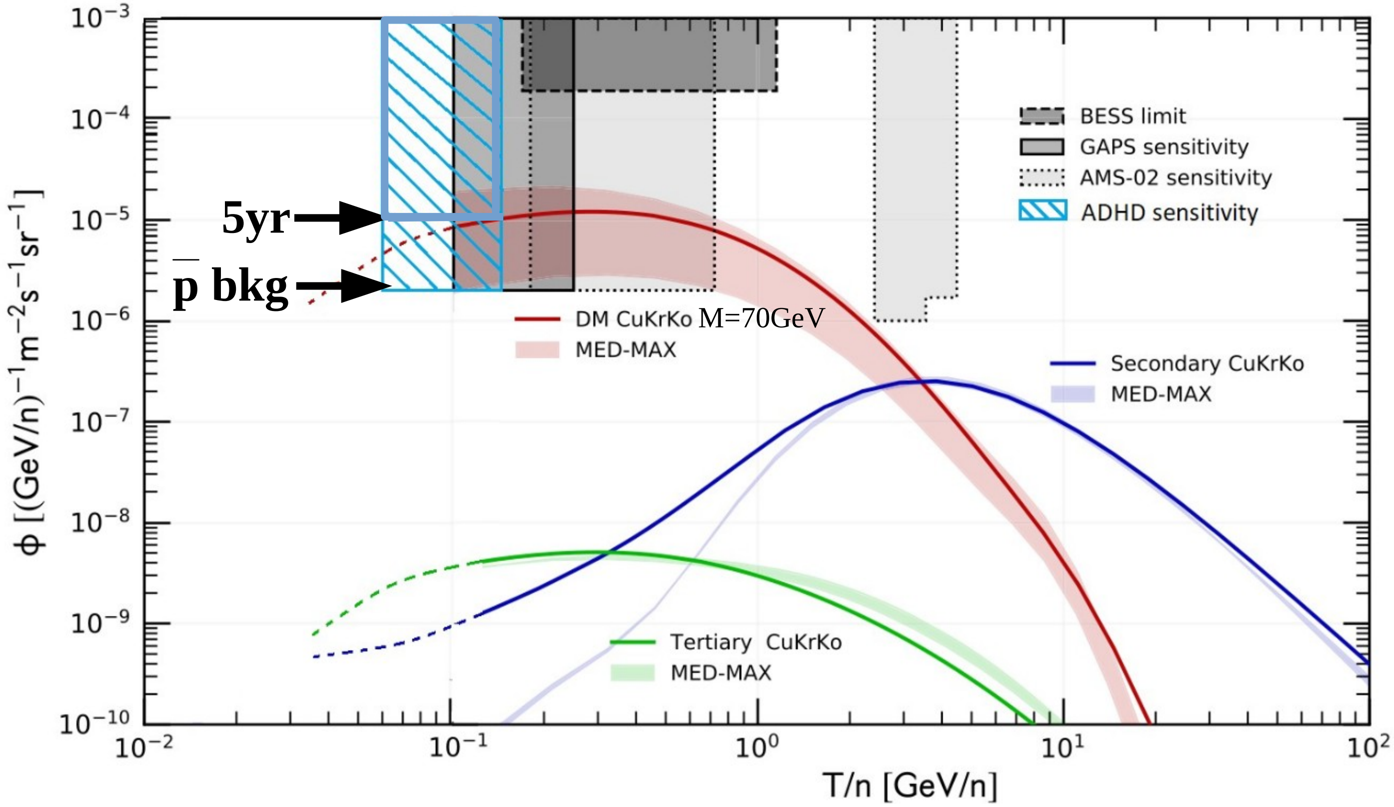




These have to be multiplied for the probability to form metastable states ~3.3%

Example of sensitivity/new measurements with 5yr data @ 0.2x0.033 $m^2$ sr:
-Antideuteron [50-150]MeV/n: $10^{-5}$ $(m^2 s\ sr\ GeV/n)^{-1}$ (<0.3 $\overline{p}$ background is expected)
-Antiproton: new measurement in 10 bins in the range [100-300] MeV with 5-10% error

# planned sensitivity

Re-adapted from:
PRD97(2018)103011




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

**Join of all the signatures in a future/ultimate Antideuteron detector?**

**ADHD**
**technological readiness level**

# The He VESSEL

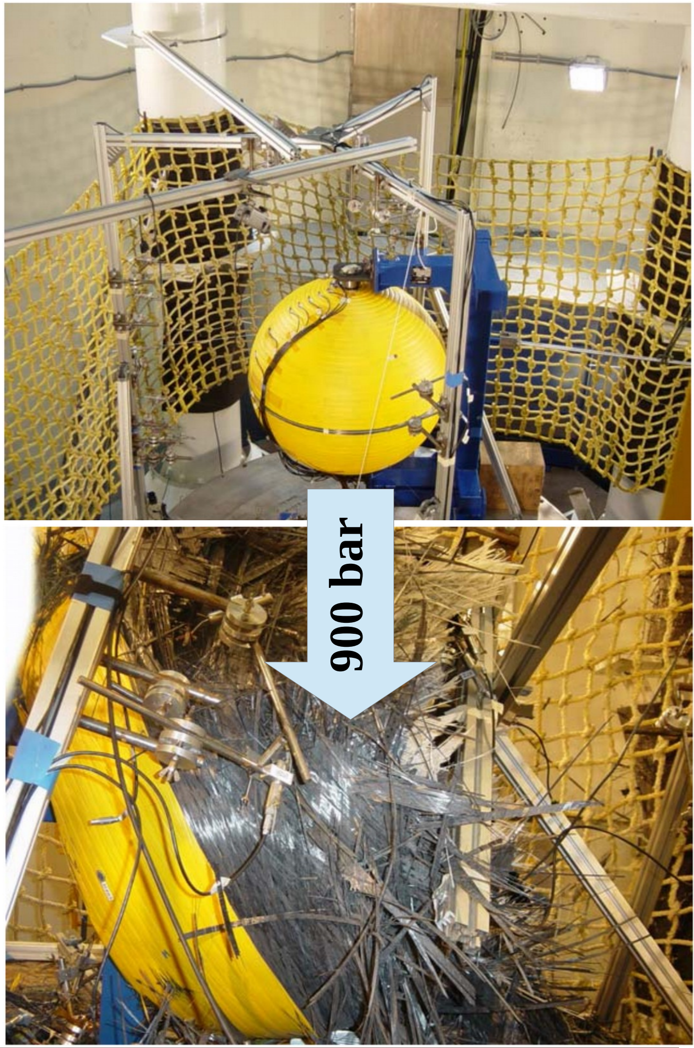
**Vessel (&ToF) sets the energy window: [50-150] MeV/n**
Wall thickness **s** x density (+ToF) => lower Energy threshold
Pressure **P** & radius **R** => upper Energy threshold
**we need a light/thin vessel + high P + large R ...**
**… and safety: ADHD gas stored energy is the same as ~ 4kg TNT**

**For cost reduction on the Ariane 5 launcher, EADS-ST intends to replace the usual and expensive titanium liner of He tank by a plastic one http://www.dtic.mil/dtic/tr/fulltext/u2/a445482.pdf**

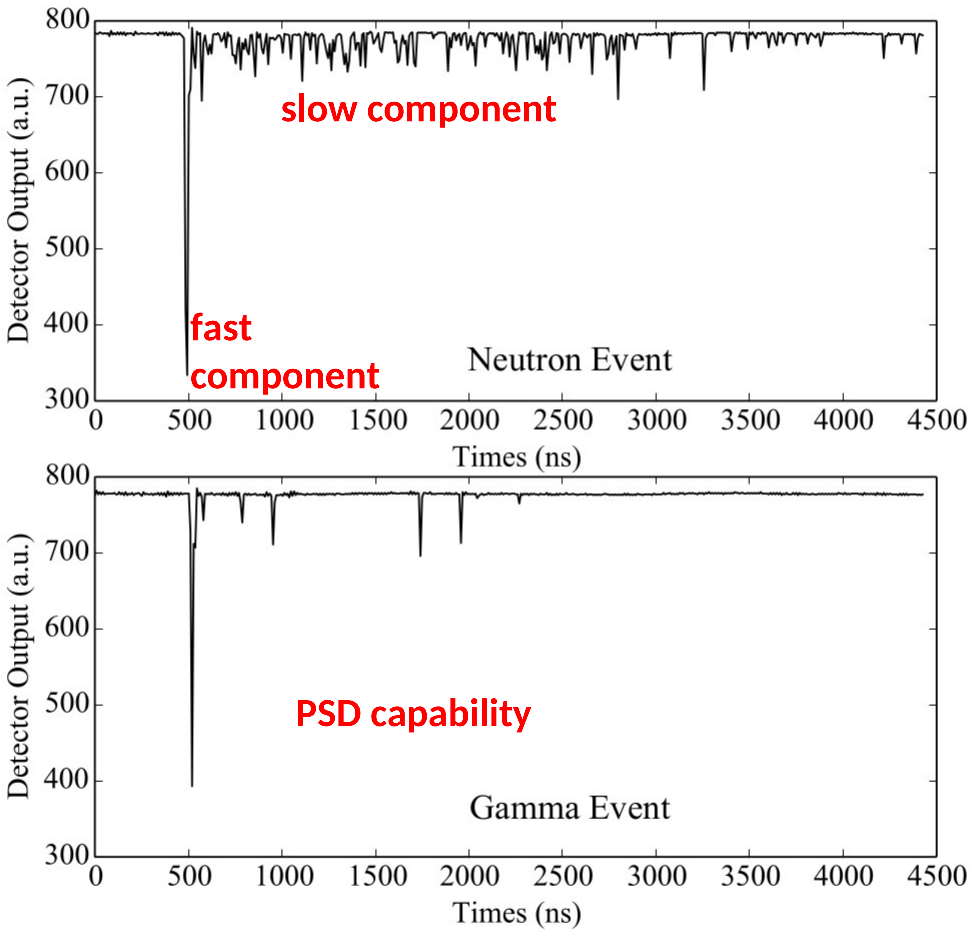
**spherical vessel $P_{burst}$ prop.to R/s**

**300L x 93kg**
**Rin=41.7cm**
**Rout=45cm**
**density ~ 1.1g/cm$^3$**
**to be loaded with He @ 400 bar (safety factor 2.2)**

**burst@900bar  R=45cm s=3.3cm**



# The He Calorimeter




He as scintillator has a strong “fast” component (tens ns, 15000 ph/MeV)

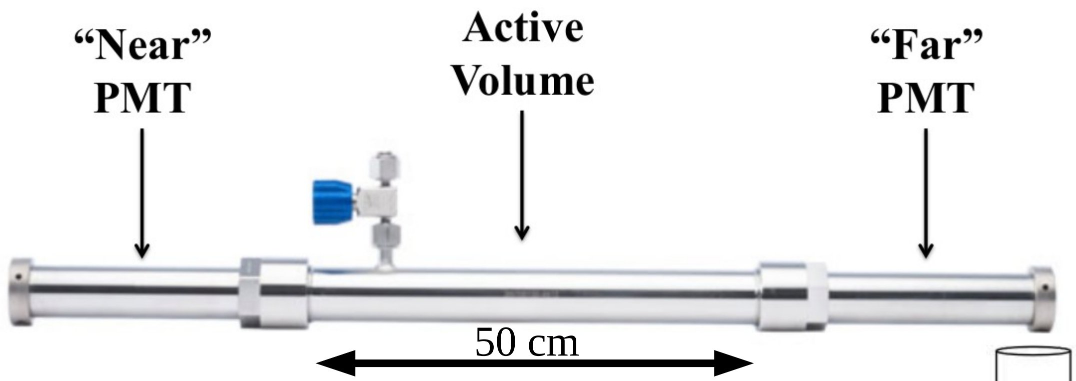
He is scintillating in VUV:
Vessel have to be PTFE coated with an organic phosphor that converted the wavelength of the scintillation light from 80 nm to 430 nm.

High pressure issue:
Most probably PMT cannot be used inside the high pressure vessel => SiPM

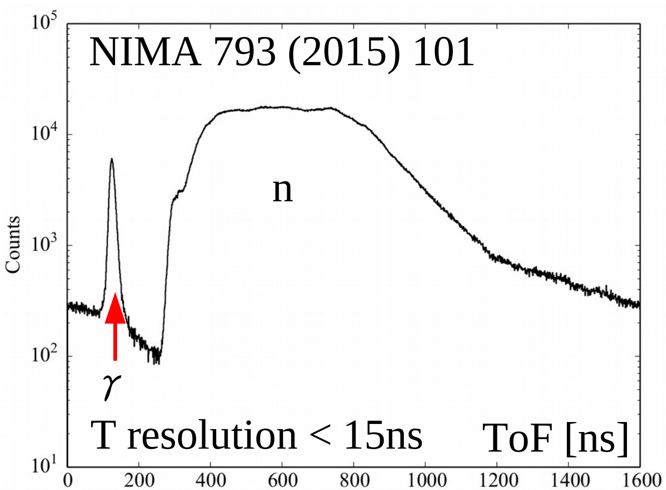
(test for a possible use of SiPM in space and their radiation tolerance are currently ongoing @ TIFPA proton beam)

# Prototype for beam test: ARKTIS B670

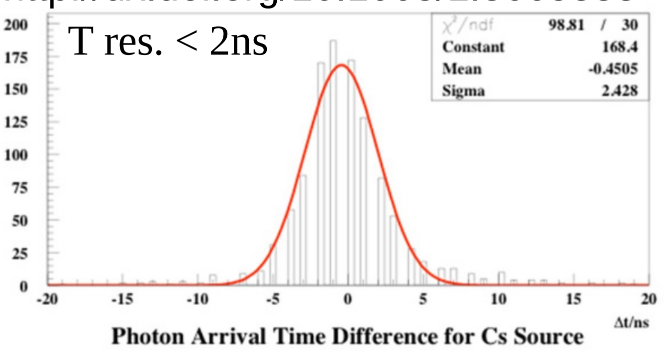
209 bar $^4$He: 0.95L
50cm x 5cm $\phi$

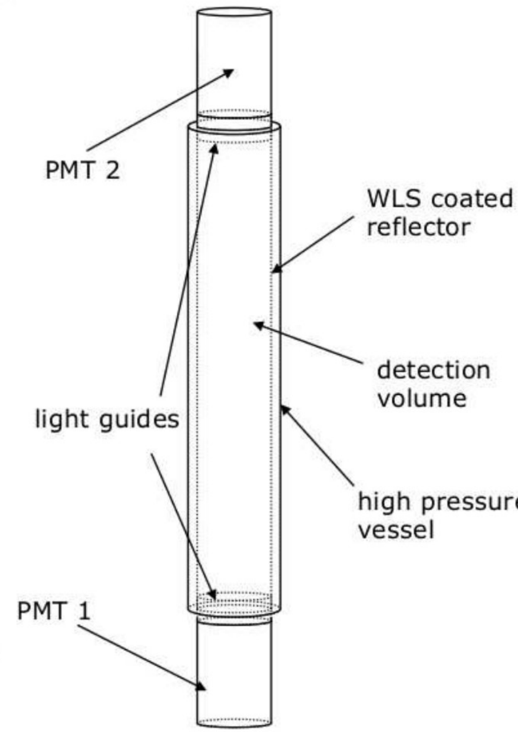



Expected time resolution: **few ns**
Energy resolution: … to be measured
some spatial resolution (?): … to be measured

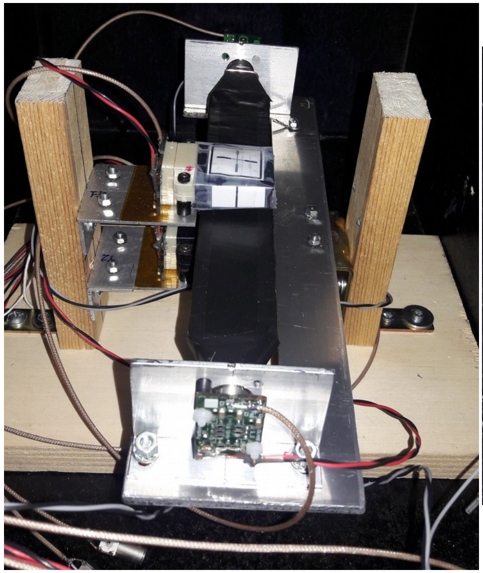


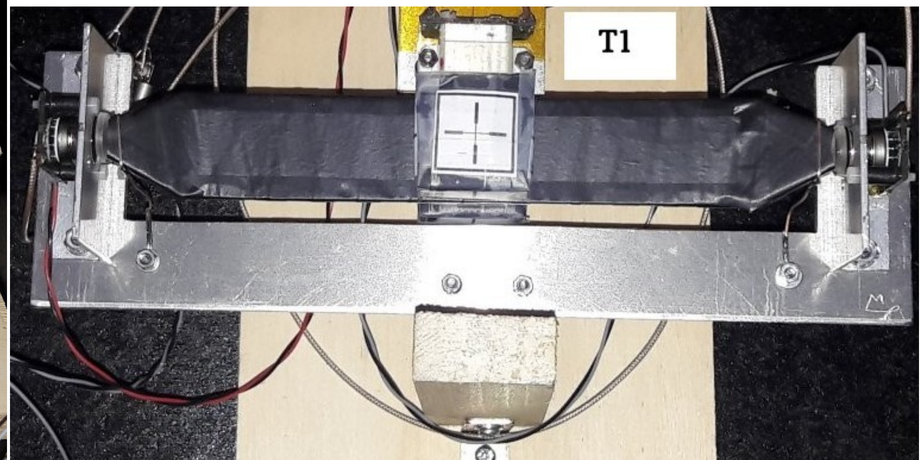

http://dx.doi.org/10.1063/1.3665333



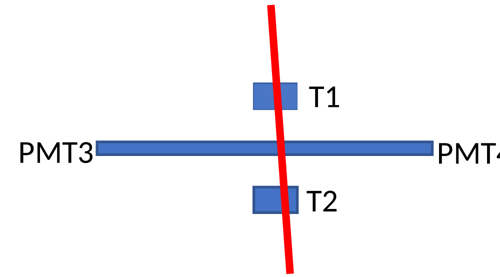
# Test of a ToF bar: Energy resolution

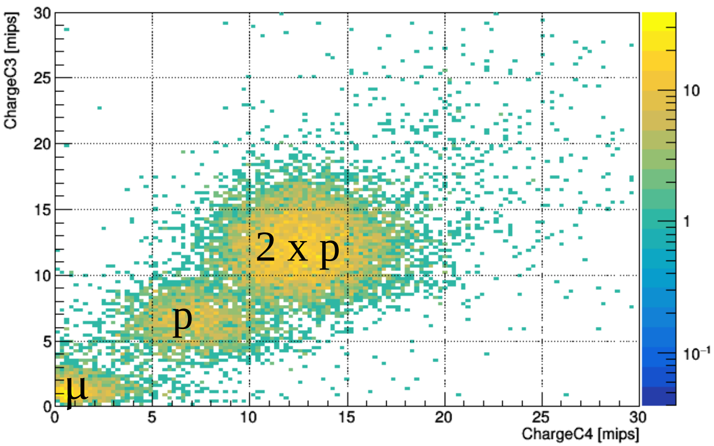


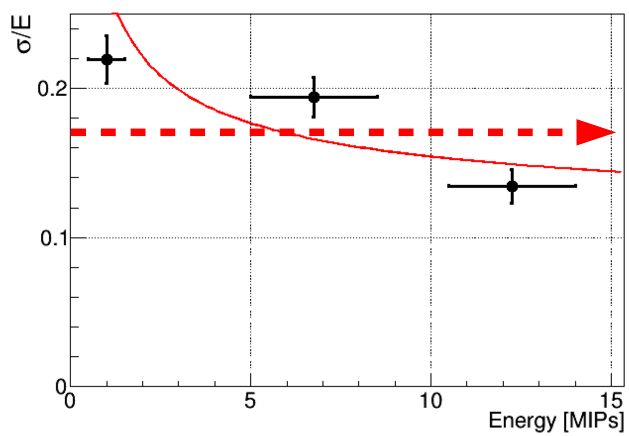



Test of a **very thin ToF** bar:
15cm x 3cm x 2mm EJ-200
2 x Hamamatsu R9880-210

- proton beam E = 62 MeV
- muons (cosmic) (MIPs)

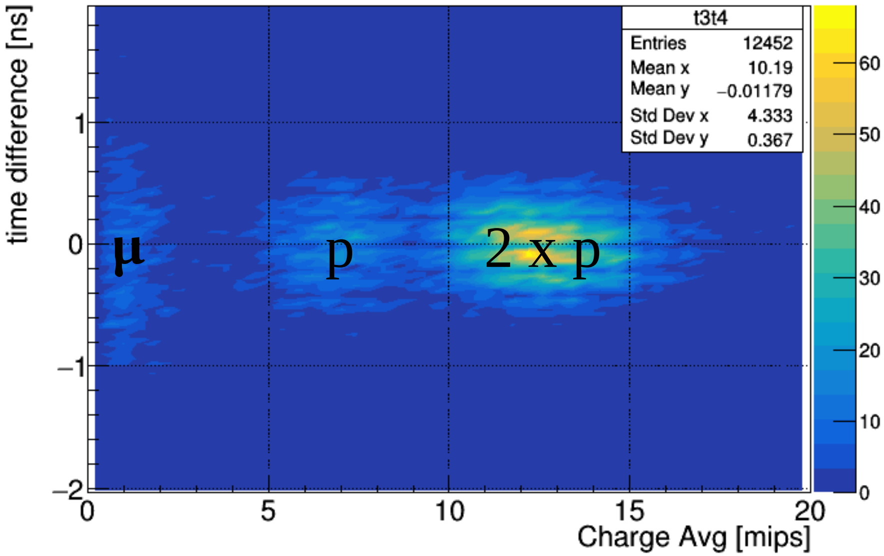


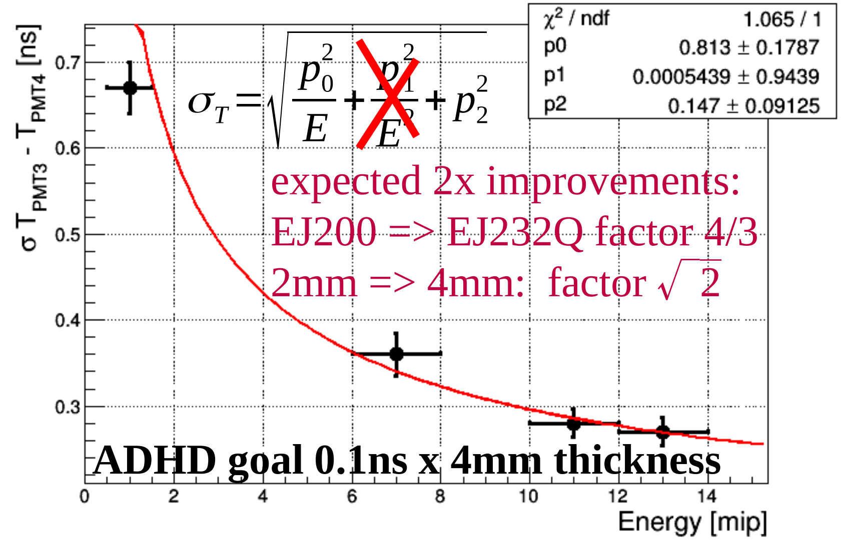



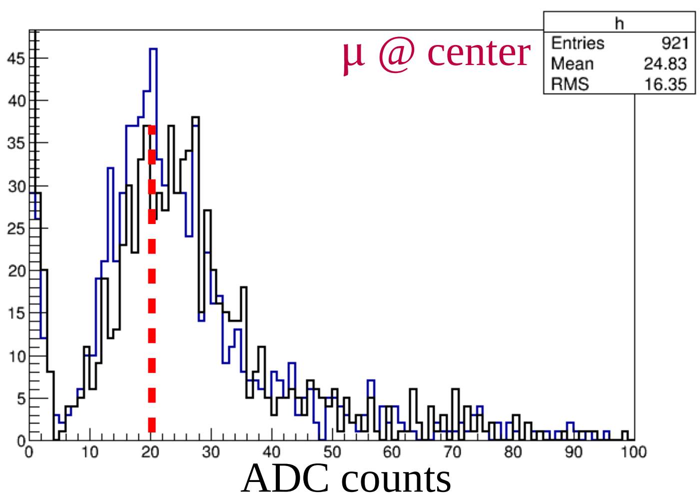



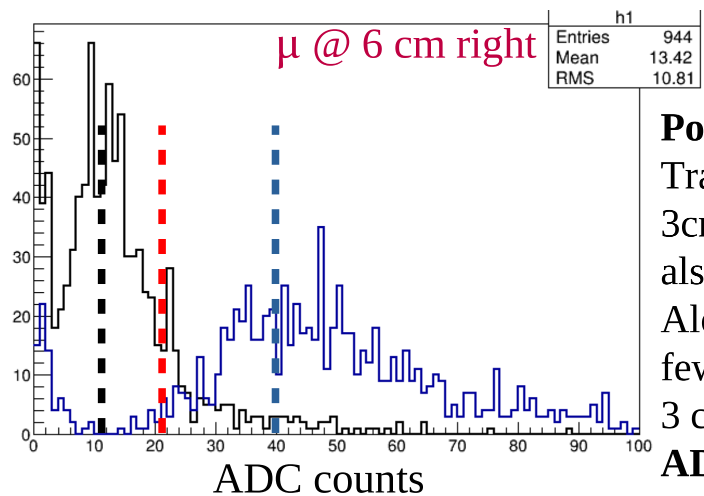

**ADHD goal already fulfilled**
10% Energy resolution in MC simulation using 3layer of 4mm each (test with 2mm).
(17% = 10% $\sqrt{3}$)
**=> reasonable to reach 5%**
number of readout channel problem: Lx5cm => 900 ch
3 cm x 15 cm ~ 12000 ch

# Test of a ToF bar: Space/Time resolution




**Position resolutions @ %:**
Transverse to the bar:
3cm/$\sqrt{12}$ ~ 1cm
also 5cm bar width is enough
Along the bar:
few cm from side amplitudes
3 cm from timing (0.1ns res)
**ADHD goal already fulfilled**

# Conclusion / to do list

ADHD is a new technique for Antideuteron identification in He target:

Result of $\bar{d}$ and $\bar{p}$ MC simulations (0.1ns x few cm ToF resolution):
- Antiproton in Antideuteron region ~1/1500 @ 65% $\bar{d}$ efficiency
- Feasible acceptance ~ 0.2$m^2$sr, 20kgHe @ 400Bar, 27$m^2$ of ToF
- $\bar{d}$ sensitivity 5y [50-150]MeV/n: $10^{-5}$ ($m^2$s sr GeV/n)$^{-1}$ (<0.3 $\bar{p}$ background is expected)
- $\bar{p}$ in 5y, new measurement in 10 bins in the range [100-300] MeV with 5 - 10% error

To do list/wishlist:
- Evaluate Proton and other Cosmic Ray pile-up background (and sensitivity): ongoing
- Test of a detector prototype based on ARKTIS B670 200Bar He scintillator:
  → cosmic muons: ongoing
  → proton beam test in Trento [50-230] MeV: scheduled in 2020
  → test to $\bar{p}$ beam: few year in the future, after prototype optimization (test also Li target)
- SiPM qualification for space and rad-tolerance: ongoing @ Trento proton beam
- ToF 0.1ns resolution: still to be proven (now ~ 0.3ns is obtained, 0.15ns as AMS-02 is feasible)
- How to manage ~1k to 10k ToF channels: still to be proven (AMS-02 ToF+ACC use 100ch)

**ADHD:** **A**ttention **D**eficit: maybe … **H**yperactivity **D**isorder: guaranteed!