GSI Helmholtzzentrum für Schwerionenforschung GmbH

Measurement of antinuclei absorption with HMPID

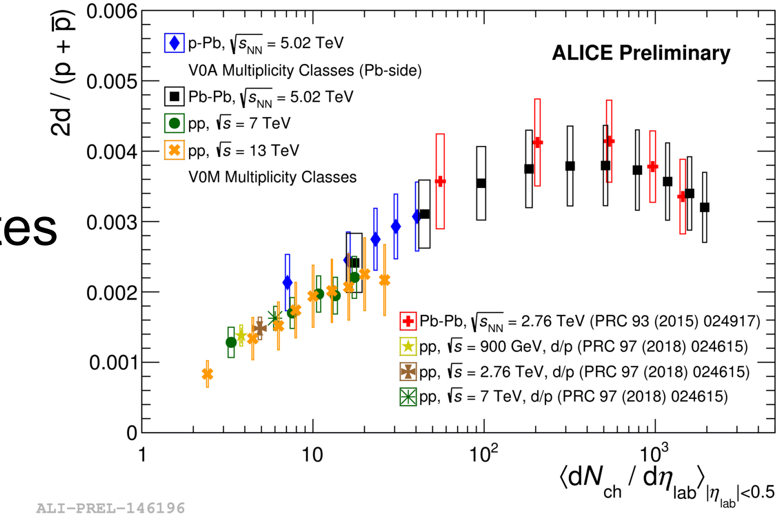
HMPID Plenary meeting

Alberto Calivà – 14 / 12 / 2018

Light nuclei production

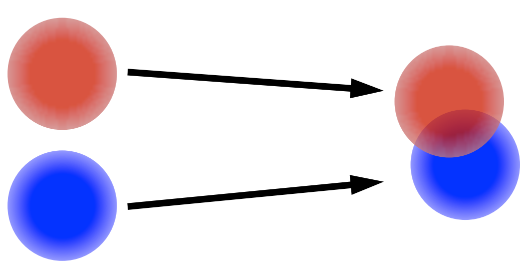
Measurement of light (anti-)nuclei production in high-energy hadronic collisions:

- ➢ Study **hadronization** for multi-baryon states
- ➢ System-size dependence of the **production mechanism**

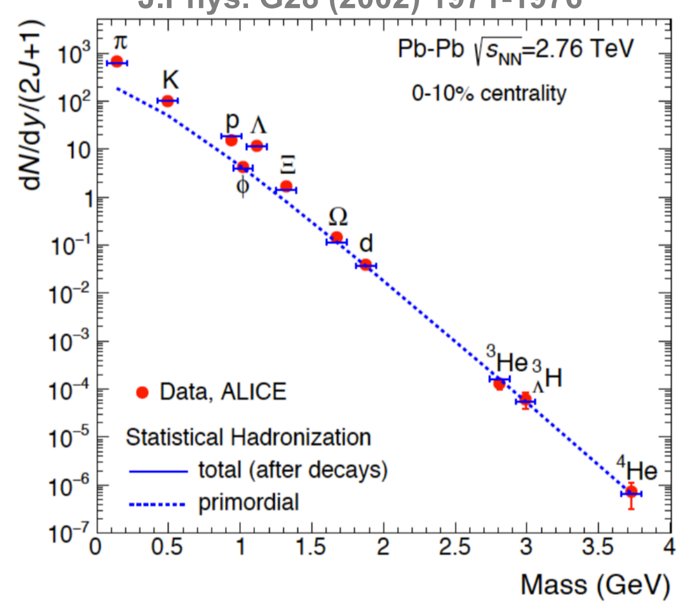


Two approaches typically used to describe light nuclei production:

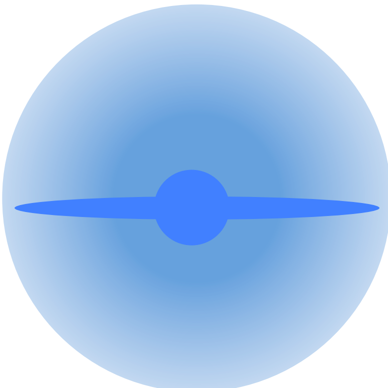
- Statistical hadronization model
- Coalescence



J.Phys. G28 (2002) 1971-1976



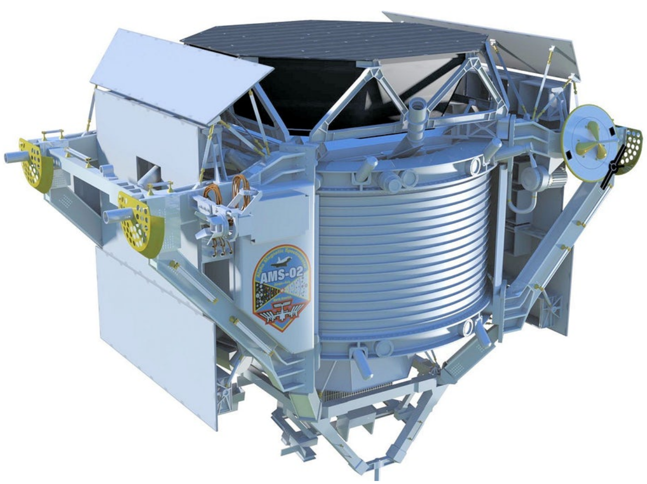
Dark matter searches



Dark matter annihilation in the galactic halo results in matter-antimatter production:

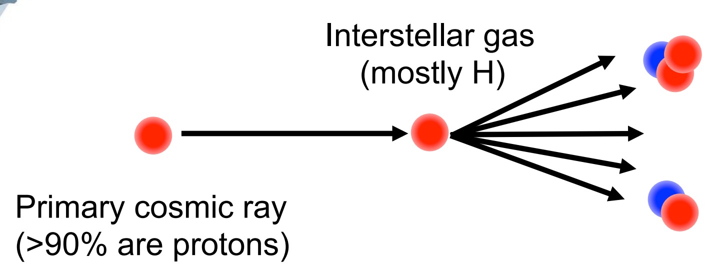
$$\chi\bar{\chi} \rightarrow \gamma\gamma,\ \mathrm{e}^{+}\mathrm{e}^{-},\ \mathrm{p}\bar{\mathrm{p}},\ \mathrm{d}\bar{\mathrm{d}},\ {}^{3}\mathrm{He}\,{}^{3}\overline{\mathrm{He}}, \ldots$$

Neutralinos (WIMPS) are the best dark matter candidates



AMS dedicated to dark matter searches in space

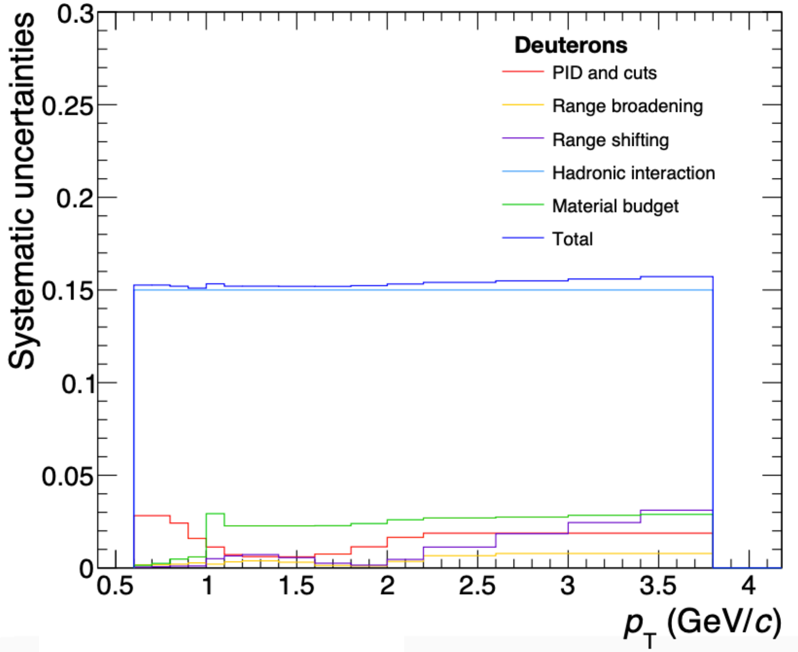
DM signal: excess in antimatter compared to its production in collisions between cosmic rays and interstellar medium



Measurement of antimatter production in pp collisions is a **fundamental baseline**

Current status

https://indico.cern.ch/event/759079/contributions/3149113/attachments/1721206/2778884/LF20180924.pdf



Poor knowledge of hadronic interaction of light nuclei with detector material and absorption cross-section of antinuclei

- Largest contribution to systematic uncertainties (15%)

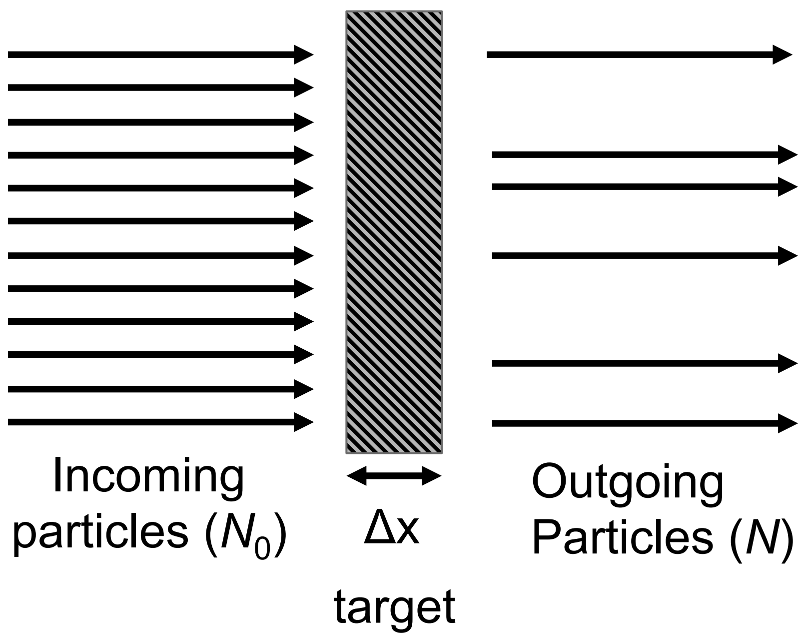
Reducing this source of syst. uncertainties for high-precision measurements in Run 3 is high priority for PWG-LF

Measurements of antideuteron absorption cross-section available:

- p = 13.3 GeV/c Nucl.Phys. B31 (1971) 253-260
- p = 25.0 GeV/c Phys.Lett. 31B (1970) 230-232

Measurement of the absorption cross section

Beam of antinuclei on a fixed target

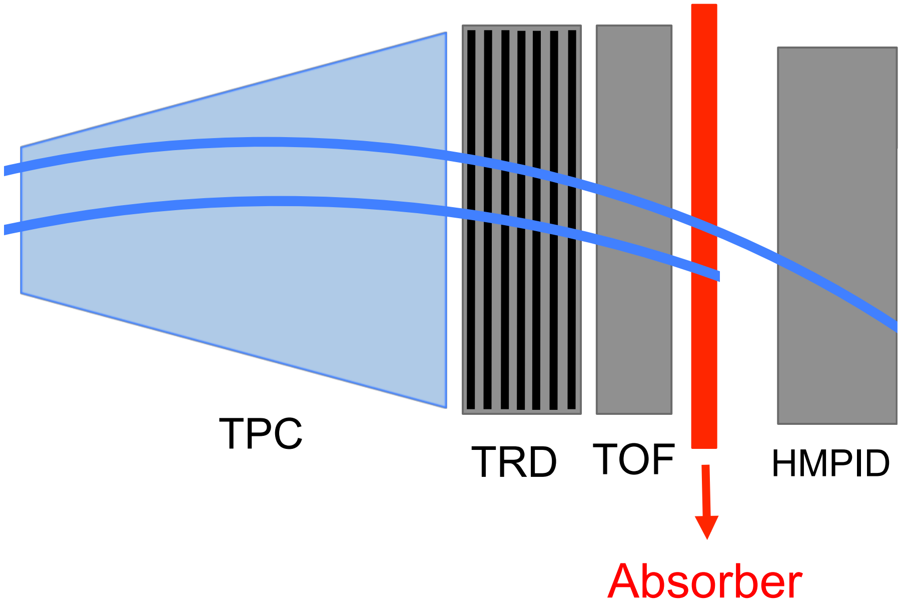


$$N = N_0 \cdot \mathrm{e}^{-\Delta x/\lambda_I}$$

$$\lambda_I = \frac{A}{\rho N_\mathrm{A} \sigma_\mathrm{h}}$$

↓ Hadronic interaction cross-section

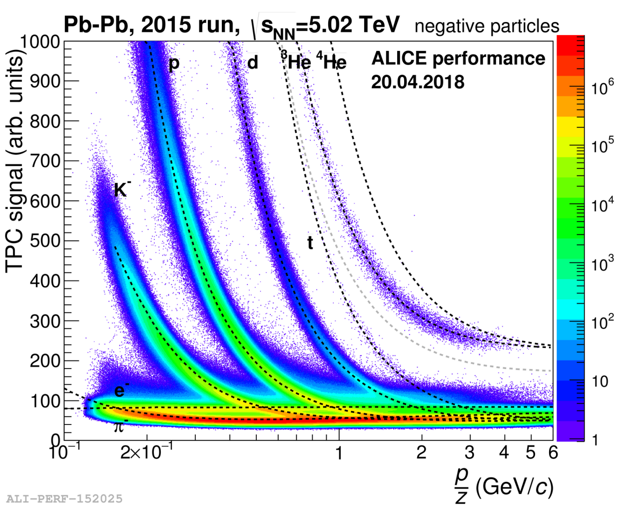
Proposed setup

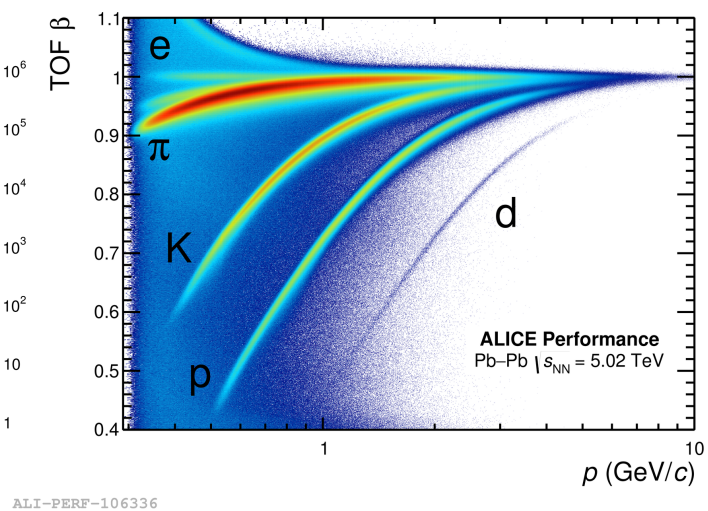


(Anti) deuterons & (anti-)^{3}He identified in the TPC, TRD & TOF

MWPC of the HMPID used to detect tracks already identified in previous detectors

➢ **no PID will be used**

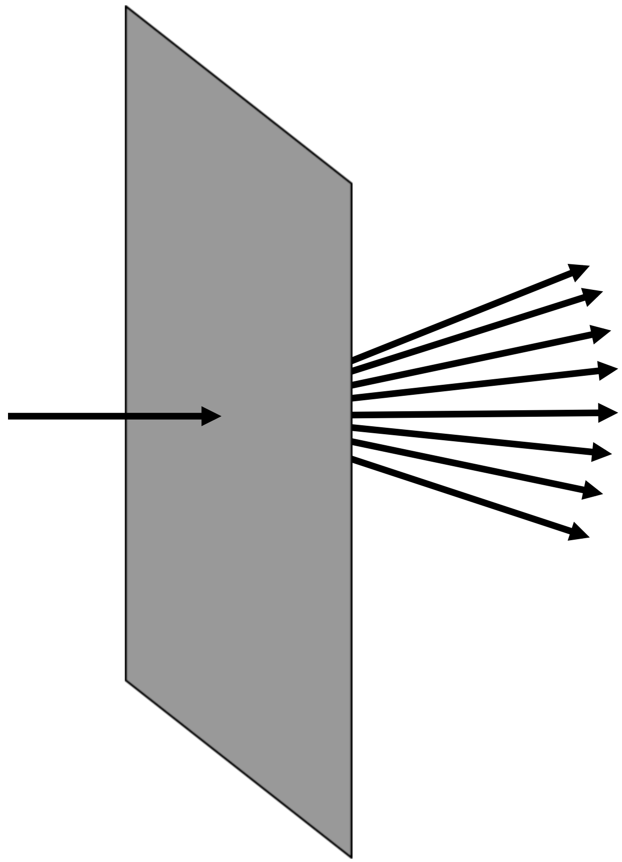




Background from TOF Mismatch:

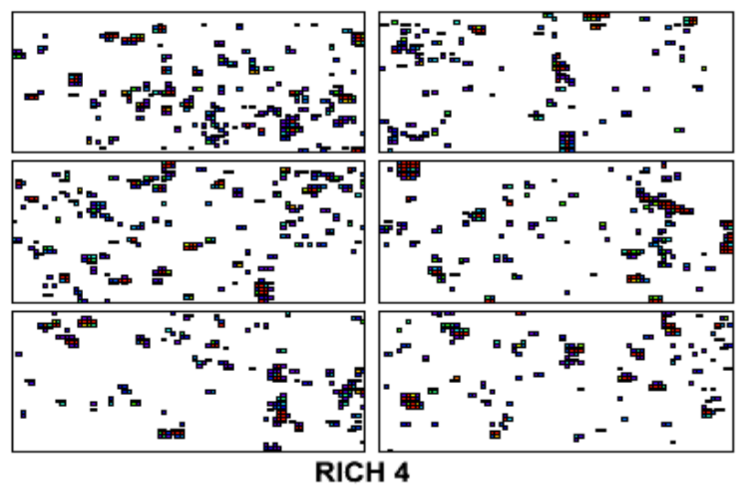
➢ Could be reduced by using the TRD

Hadronic shower



Interactions between incoming particles and nuclei in the absorber will produce hadronic cascades

These events should be clearly visible in the HMPID (high granularity)



Studies based on simulations will be done to refine analysis technique to distinguish these events

Absorber material

Study of the optimal material is ongoing

Several options have been considered so far:

Polyethylene (C_2H_4), Si, Al, C (Graphite)

Main interest in hadronic interaction:

- Small hadronic radiation length (λ_I)
- Large electromagnetic radiation length (λ_{em})
  - Suppress e.m. background

Absorber material

Polyethylene

Atomic and nuclear properties of polyethylene [$(CH_2CH_2)_n$]

Quantity	Value	Units	Value	Units
<Z/A>	0.57034			
Specific gravity	0.8900	g cm^{-3}		
Mean excitation energy	57.4	eV		
Minimum ionization	2.079	MeV $g^{-1}cm^2$	1.850	MeV cm^{-1}
Nuclear collision length	56.1	g cm^{-2}	63.05	cm
Nuclear interaction length	78.5	g cm^{-2}	88.18	cm
Pion collision length	83.7	g cm^{-2}	94.07	cm
Pion interaction length	110.4	g cm^{-2}	124.0	cm
Radiation length	44.77	g cm^{-2}	50.31	cm
Critical energy	101.79	MeV (for e^-)	99.13	MeV (for e^+)
Molière radius	9.33	g cm^{-2}	10.48	cm
Plasma energy $\hbar\omega_p$	20.53	eV		
Muon critical energy	1282.	GeV		

http://pdg.lbl.gov/2017/AtomicNuclearProperties/HTML/polyethylene.html

Silicon

Atomic and nuclear properties of silicon (Si)

Quantity	Value	Units	Value	Units
Atomic number	14			
Atomic mass	28.0855(3)	g $mole^{-1}$		
Specific gravity	2.329	g cm^{-3}		
Mean excitation energy	173.0	eV		
Minimum ionization	1.664	MeV $g^{-1}cm^2$	3.876	MeV cm^{-1}
Nuclear collision length	70.2	g cm^{-2}	30.16	cm
Nuclear interaction length	108.4	g cm^{-2}	46.52	cm
Pion collision length	96.2	g cm^{-2}	41.29	cm
Pion interaction length	137.7	g cm^{-2}	59.14	cm
Radiation length	21.82	g cm^{-2}	9.370	cm
Critical energy	40.19	MeV (for e^-)	39.05	MeV (for e^+)
Molière radius	11.51	g cm^{-2}	4.944	cm
Plasma energy $\hbar\omega_p$	31.05	eV		
Muon critical energy	582.	GeV		
Melting point	1687.	K	1414.	C
Boiling point @ 1 atm	3538.	K	3265.	C
Index of refraction (Na D)	3.950			

http://pdg.lbl.gov/2018/AtomicNuclearProperties/HTML/silicon_Si.html

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Absorber material

Graphite

Atomic and nuclear properties of carbon (graphite) (C)

Quantity	Value	Units	Value	Units
Atomic number	6			
Atomic mass	12.0107(8)	g mole^{-1}		
Specific gravity	2.210	g cm^{-3}		
Mean excitation energy	78.0	eV		
Minimum ionization	1.742	MeV g^{-1}cm^{2}	3.850	MeV cm^{-1}
Nuclear collision length	59.2	g cm^{-2}	26.79	cm
Nuclear interaction length	85.8	g cm^{-2}	38.83	cm
Pion collision length	86.5	g cm^{-2}	39.12	cm
Pion interaction length	117.8	g cm^{-2}	53.30	cm
Radiation length	42.70	g cm^{-2}	19.32	cm
Critical energy	81.74	MeV (for e^-)	79.51	MeV (for e^+)
Molière radius	11.08	g cm^{-2}	5.012	cm
Plasma energy $\hbar\omega_p$	30.28	eV		
Muon critical energy	1057.	GeV		
Sublimination temperature (@ 1 atm)	4098.	K	3825.	C

http://pdg.lbl.gov/2018/AtomicNuclearProperties/HTML/carbon_graphite_C.html

Aluminum

Atomic and nuclear properties of aluminum (Al)

Quantity	Value	Units	Value	Units
Atomic number	13			
Atomic mass	26.9815385(7)	g mole^{-1}		
Specific gravity	2.699	g cm^{-3}		
Mean excitation energy	166.0	eV		
Minimum ionization	1.615	MeV g^{-1}cm^{2}	4.358	MeV cm^{-1}
Nuclear collision length	69.7	g cm^{-2}	25.82	cm
Nuclear interaction length	107.2	g cm^{-2}	39.70	cm
Pion collision length	95.6	g cm^{-2}	35.41	cm
Pion interaction length	136.7	g cm^{-2}	50.64	cm
Radiation length	24.01	g cm^{-2}	8.897	cm
Critical energy	42.70	MeV (for e^-)	41.48	MeV (for e^+)
Molière radius	11.93	g cm^{-2}	4.419	cm
Plasma energy $\hbar\omega_p$	32.86	eV		
Muon critical energy	612.	GeV		
Melting point	933.5	K	660.3	C
Boiling point @ 1 atm	2792.	K	2519.	C

http://pdg.lbl.gov/2018/AtomicNuclearProperties/HTML/aluminum_Al.html

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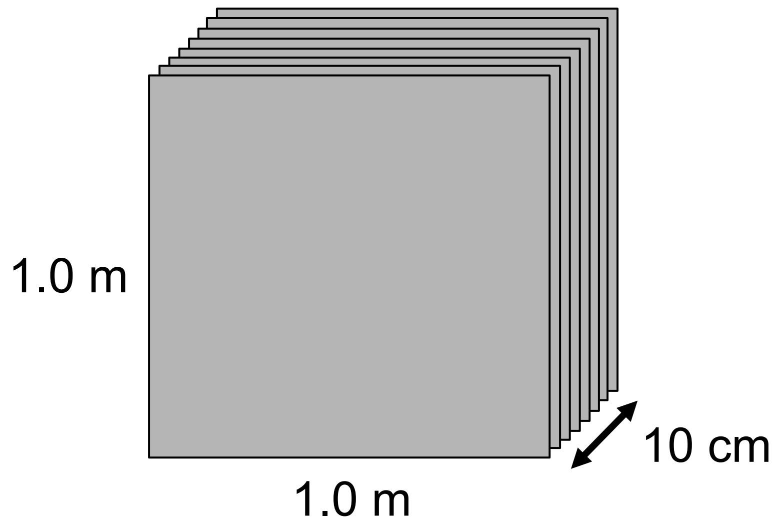
http://pdg.lbl.gov/2018/AtomicNuclearProperties/HTML/aluminum_Al.html

- **Graphite** is the best candidate at the moment
- Silicon and aluminum are also good options

Structure of the absorber

Available space between TOF frame and HMPID ≈ 10 cm (close to TOF)



Using **Graphite**

Δx = 10 cm ≈ 1/3 of the (hadronic) radiation length

Density = 2.27 g/cm^3

Absorber weight: 227 kg !!

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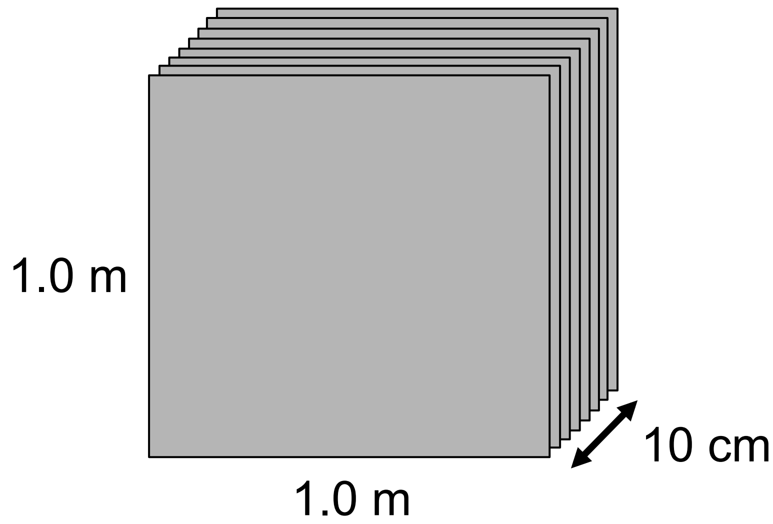

Using **Graphite**

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Density = 2.27 g/cm^3

Absorber weight: 227 kg !!

Flexible graphite foils could be used to make a stack:

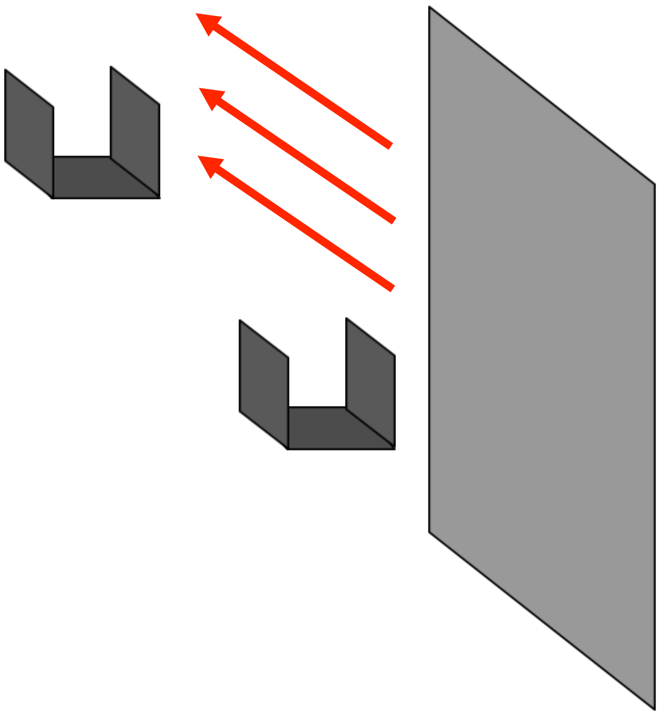
- Chemical resistant
- Heat and flame resistant
- No toxicity
- Low creep relaxation and no aging

Structure of the absorber

Proposed support structure for the absorber:

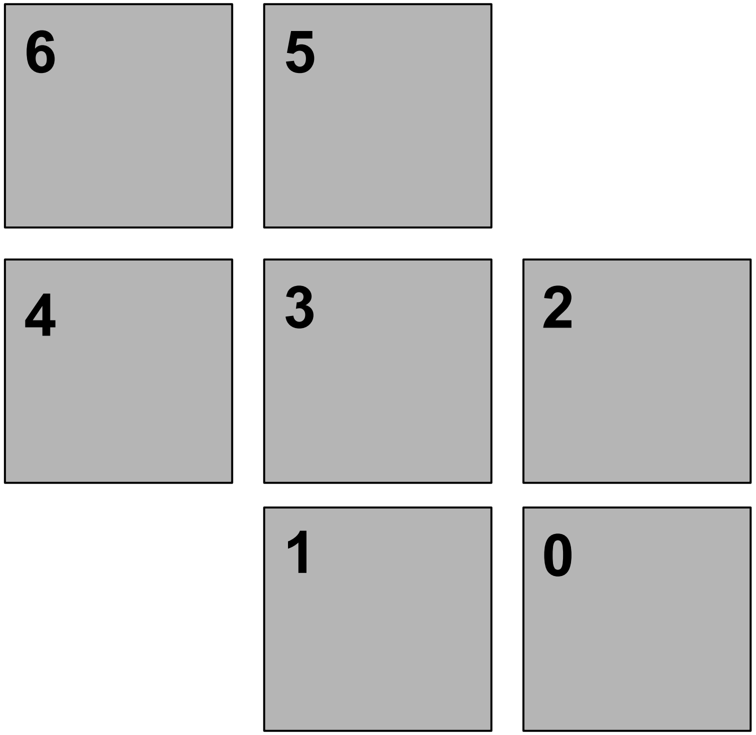
- U-shaped supports attached to external part of the TOF frame will be used as rails

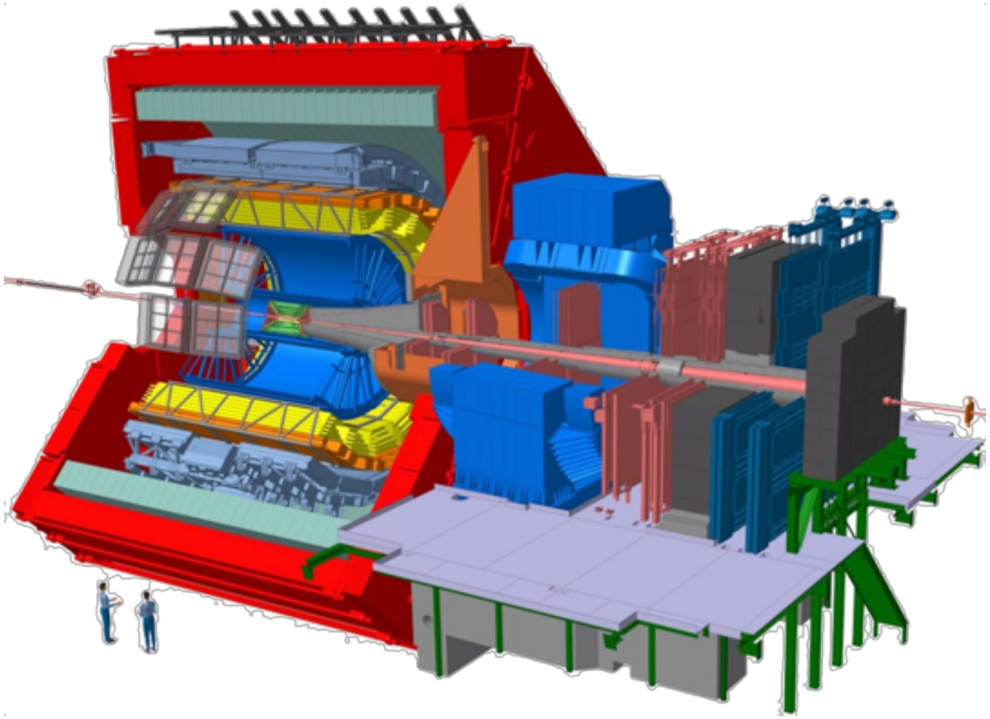
The layers of absorbed will be dragged in using these rails



Feasibility confirmed by Antonio Lafuente (CERN engineer for ALICE)

Installation





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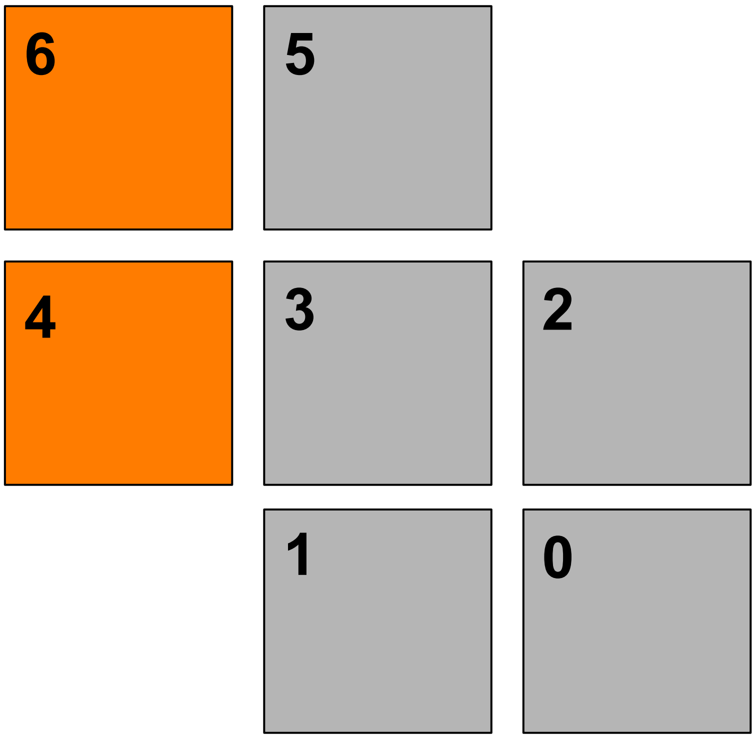
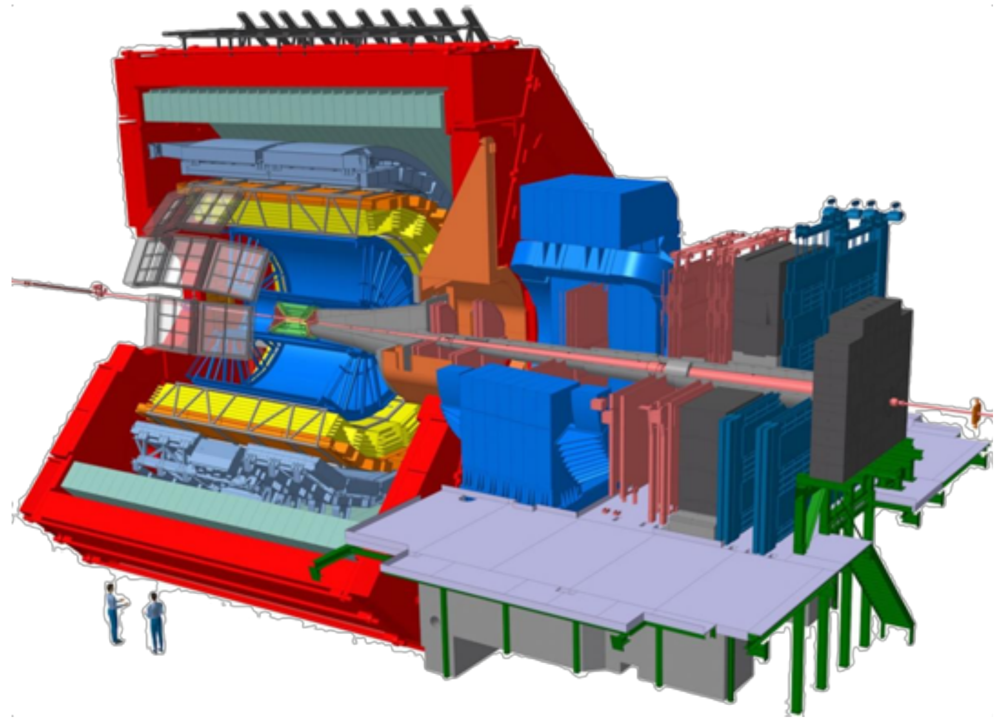




Two modules should be equipped with the absorbers: modules 4 and 6

Leakage in the radiators: currently cannot be used for PID

Access relatively easier compared to other modules

Expected statistical precision

$$N_{\mathrm{A,incoming}}^{\mathrm{absorber}} = N_{\mathrm{A,present}} \times \underbrace{0.05}_{\text{HMPID acceptance relative to TPC}} \times \underbrace{10}_{\text{Readout rate (in Pb-Pb)}} \times \underbrace{f}_{\text{Fraction of modules with absorber (2 / 7)}}$$

HMPID acceptance relative to TPC

Readout rate (in Pb-Pb)

Fraction of modules with absorber (2 / 7)

$$N_{\mathrm{A}}^{\mathrm{HMPID}} = N_{\mathrm{A,present}} \times 0.05 \times 10 \times f \times \underbrace{\epsilon}_{\text{Fraction of antinuclei absorbed in the material}}$$

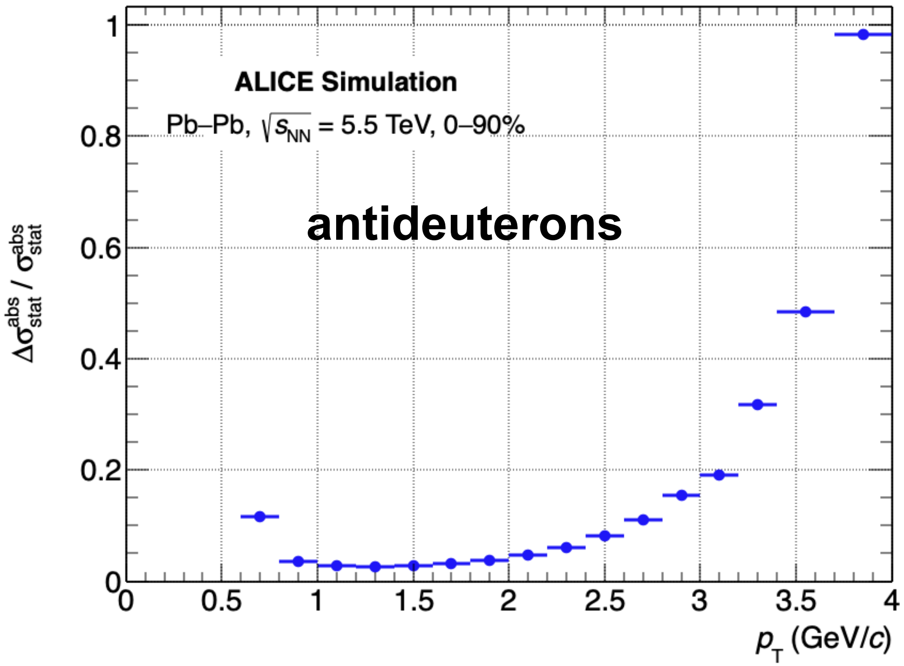
Fraction of antinuclei absorbed in the material

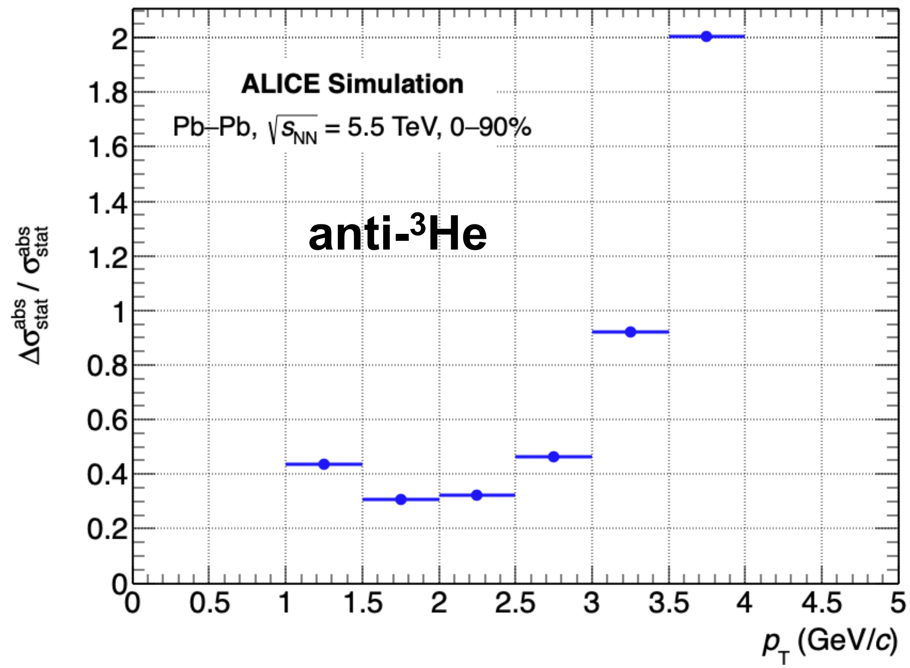
1/3 of antinuclei are assumed to be absorbed in this calculation

Relative statistical uncertainty:

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{\frac{1}{N} + \frac{1}{N_0}}}{\log\left(\frac{N_0}{N}\right)}$$

Expected statistical precision





High-precision measurement of antideuteron absorption cross section in the range $1 < p_T < 3.5$ GeV/c

Rel. uncertainty for ^{3}He is ~30-40% in the same range

Estimates of expected precision of antiprotons are ongoing

Summary

The knowledge of antimatter absorption cross section is crucial for light nuclei measurements

This measurement will be accomplished with **unprecedented precision** using the HMPID

Scientific impact of this measurement:

- Extend existing measurements to low energy
- Relevant also for astrophysics (AMS-02, cosmic ray propagation, …)

Technical details regarding the installation are under discussion

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Thank you for your attention!